A GUIDE FOR WASTE MANAGEMENT IN THE FOOD PROCESSING INDUSTRY

edited by

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PREFACE

The Food Processing Industry has recognized the problems connected with treatment and disposal of wastes from the preparation and preservation of the foods it produces. It has initiated studies designed to establish the technical factors involved in handling and disposing of liquid and solid wastes by methods which prevent water pollution or other nuisance problems. This publication represents the combined efforts of the many engineers and scientists who have conducted, or are now engaged in, these studies.

It is not the purpose of this publication to present a complete discussion of the many factors involved in treatment and disposal of food processing wastes, but to offer a practical guide to management and operating personnel in the food processing plants. It is recognized that individual waste problems may present unique circumstances not considered in this Guide. However, experience has shown that all such problems have factors in common. It is the purpose of this Guide to discuss the nature and source of the wastes and to describe in-plant practices which are known to improve waste disposal situations.

Practical procedures are discussed which may reduce the volume and the strength of the waste load, and thus, reduce total waste management costs. Water conservation is also discussed in connection with its effect on waste problems. Because the recycling of process waters, as a means of water conservation, necessitates the use of chlorine as a sanitizing agent, chlorination procedures and controls are discussed in detail.

The section on "Methods of Treatment and Disposal" is not intended to be a comprehensive presentation of the knowledge accumulated in this field. However, the principal methods of treatment generally recognized to be of value are outlined. A supplementary publication, *Guide to Literature on Waste Management for the Food Processing Industry, 1900-1975,* lists selected references which given detailed information regarding the principles and mechanics of these methods, as well as other studies.

Acknowledgements are due to past and present staff members of the National Food Processors Association's Research Laboratories for their efforts in developing and accumulating the information which is included in the Guide. Much of the information contained in the Guide has been gleaned from the technical writings of scientists who have concerned themselves with the water and waste problems of the food industries. Acknowledgements are due also to members of the National Food Processors Association's former Waste Management Committee and current Technical Committee on Environmental Research whose individual and collective advice and criticism constituted a valuable contribution to the effort.

SECTION 1

LIQUID AND SOLID WASTES FROM FOOD PROCESSING OPERATIONS

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SECTION 1

LIQUID AND SOLID WASTES
FROM
FOOD PROCESSING OPERATIONS

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1.0

INTRODUCTION

Water is a natural resource which, like all other natural resources, is available in limited quantity. Of all the water present on Earth, an estimated 97.13% exists in the oceans, 2.24% is contained in polar icecaps, and 0.612% is in the form of groundwater. The lakes of the world contain but 0.009% of the water, while a scant 0.0001% flows in streams and rivers. These values are illustrated in Figure 1.01. Of the fresh water available in the United States, 95% exists as groundwater and only about 5% as surface water.

The food processing industry requires large volumes of clean water for the preparation and preservation of canned, cured, and frozen foods. According to the 1967 Census of Manufacturers[1], the food and kindred products industries (SIC[2] code number 20) rank fifth among industrial water users and wastewater dischargers, having used a total of 811 billion gallons of water and having discharged 753 billion gallons of wastewater during 1968. The canned, cured and frozen foods segment (SIC code 203) used 129 billion gallons of water and discharged 120 billion gallons of wastewater during the same period (Table 1.01).

Industrial use of water invariably results in the addition of pollutants to the water. Thus, wastewaters discharged by industries can be a serious environmental problem. Fortunately, most of the pollutants are removed from industrial wastes prior to discharge into receiving waters. The sources, quantities, and points of disposition of food processing wastewaters are summarized in Table 1.02. The method of treatment used by an individual processor is related to the location in which the plant is situated. Plants in urban areas are generally served by publicly-owned treatment works (POTW), while plants located in rural areas use several methods, including ponds of all types and land irrigation. Clean wastewaters or wastewaters treated by other means are discharged directly to receiving waters.

Despite the predominance of waste treatment, water pollution is still of major concern. For this reason water pollution abatement is emphasized throughout this section and generally throughout this Guide. By identifying the sources of pollutants, enumerating the factors which influence their generation, and outlining methods by which wastes can be reduced (Section 2) and treated (Section 4), it is hoped that implementation of water pollution abatement programs within the food processing industry can be assisted.

The second environmental problem area faced by the food industry deals with the disposal of food processing residuals. (Residuals are defined as those materials which remain after processing a primary product.) In some cases residuals are utilized for by-products, such as corn husks and cobs for cattle-feed, and therefore pose few problems of disposal. However, residual materials frequently have no utility and must be disposed of in a manner which will preclude environmental pollution and public health concern.

Food processing residuals generally possess high moisture contents. Disposal problems are attributable to the water content, coupled with the large quantities of residuals that are normally generated within a short period of time. Land disposal techniques, if improperly conducted, may result in the release of liquid (leachate) which can pollute both surface and ground waters. Improper storage or open dumping

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1. *1967 Census of Manufactures: Water Use in Manufacturing.* U.S. Department of Commerce, Bureau of the Census. Washington, D.C. 1971.
2. SIC: Standard Industrial Classification; a system developed to classify industries according to activity, product classes, etc. See the *Standard Industrial Classification Manual,* U.S. Department of Commerce.

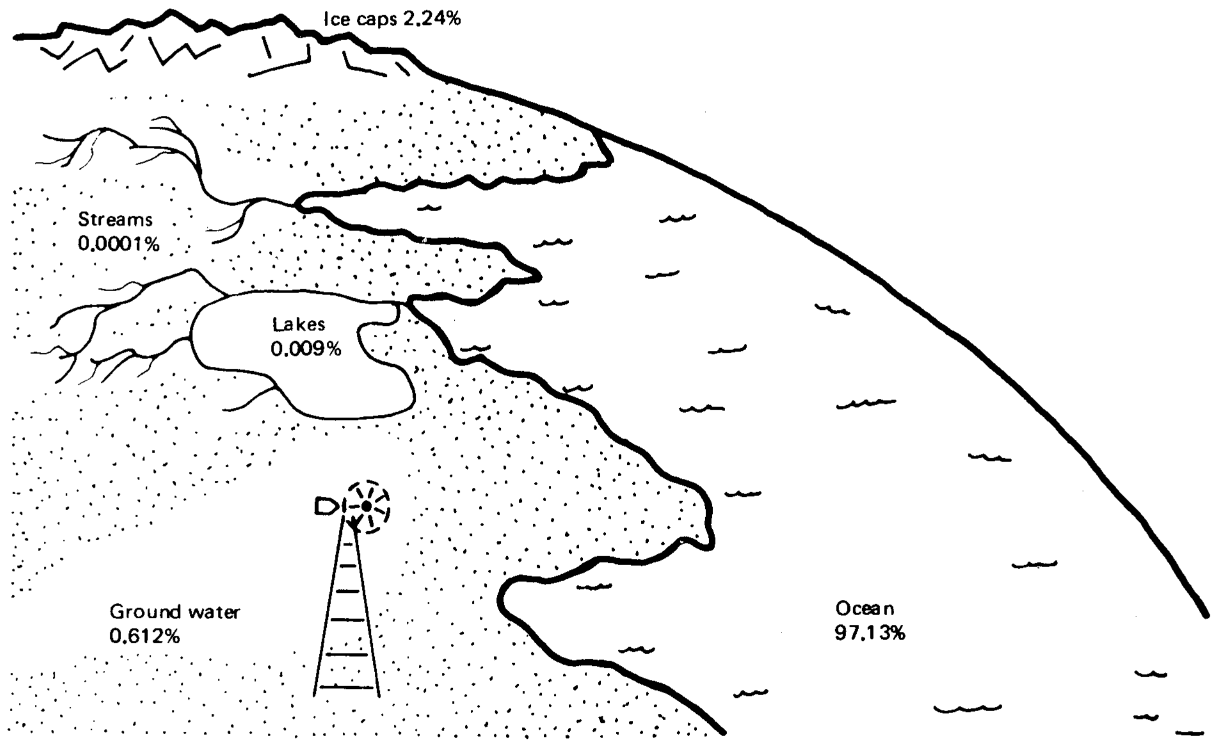

Figure 1.01. Distribution of the world's water supply.

will result in the generation of odors and the attraction of flies and rodents, thereby creating problems of public health significance. To assist in the prevention of these occurrences, recommendations are offered for in-plant handling of solid residuals (Section 2.3) and their disposal (Section 5); the quantities of residuals and factors influencing their generation are discussed in this section.

1.01 Standard Industrial Classification (SIC)

The food processing industry includes a wide variety of operations and commodities, all of which are listed under Major Group 20 – Food and Kindred Products – in the *Standard Industrial Classification Manual.* This major group is subdivided into group numbers to cover broad product classes as follows:

201 Meat Products
202 Dairy Products
203 Canned and Preserved Fruits and Vegetables
204 Grain Mill Products
205 Bakery Products
206 Sugar and Confectionary Products
207 Fats and Oils
208 Beverages
209 Miscellaneous Food Preparations and Kindred Products

This Guide is directed primarily toward Group Numbers 203 and 209. Nevertheless, processors of foods in the other groups or product classes will find the information contained herein generally useful and, in many cases, directly applicable to their operations.

Each of the above groups are further subdivided into industry numbers which reflect specific types of commodities.

TABLE 1.01
WATER INTAKE AND WASTEWATER DISCHARGE
BY MAJOR INDUSTRIAL GROUPS – 1968[1]

SIC number and description		Water intake (billion gal)	Water discharge (billion gal)
All industries		15,467	14,276
20	Food and kindred products	811	753
	203 Canned, cured and frozen	129	120
26	Paper and allied products	2,252	2,078
28	Chemicals and allied products	4,476	4,175
29	Petroleum and coal products	1,435	1,217
32	Stone, clay and glass products	251	218
33	Primary metals	5,005	4,696

1. Selected values from *1967 Census of Manufactures: Water Use in Manufacturing.* U.S. Department of Commerce, Bureau of the Census. Washington, D.C. 1971.

TABLE 1.02
DISPOSAL SITES AND VOLUMES
OF FOOD PROCESSING WASTEWATERS

	Process water		Clean water		Total	
Disposal to:	Bil. Gal.	%	Bil. Gal.	%	Bil. Gal.	%
SIC 203 plants (fruit, vegetable, specialty)						
POTW	43	51	9	30	52	46
Waterbody	16	19	16	53	32	28
Land	25	30	5	17	30	26
Total	84		30		110	
Seafood plants						
POTW	2.4	23	0.3	3	2.7	14
Waterbody	8.2	77	8.8	97	17.	86
Land	.02	.1	0	0	.02	.1
Total	11		9		20	

Source: Unpublished data, National Food Processors Association. Industry survey on groundwater monitoring. 1977.

TABLE 1.03
FOOD PROCESSING INDUSTRY:
PRODUCT CLASSES AND VALUES[1]

Code[2]	Product Class	Value of Products[3]
2032	Canned specialties	1,629.9
2033	Canned fruits and vegetables	3,922.9
2034	Dehydrated fruits, vegetables and soup mixes	625.6[4]
2035	Pickles, sauces, and salad dressings	1,165.1
2037	Frozen fruits, vegetables	1,648.7
2038	Frozen specialties	1,742.6
2091	Canned and cured seafood, soup (not frozen)	518.3
2092	Fresh or frozen packaged fish	978.3

1. From: U.S. Department of Commerce, Bureau of Census. 1972 Census Report.
2. Standard Industrial Classification code.
3. Value in millions of dollars.
4. Value of shipments.

Those of primary concern are listed in Table 1.03 and described below.

1.011 CANNED SPECIALTIES – SIC 2032

This code includes establishments primarily engaged in canning specialty products, such as baby foods, "native foods," health foods, and soups except seafood. Establishments primarily engaged in canning seafoods other than frozen are classified in Industry 2091, frozen seafoods in Industry 2092, and those primarily engaged in quick freezing canned specialties in Industry 2038.

Production of canned specialties (primary products) in 1972 represented 81 percent of this industry's total production. Secondary products consisted mainly of canned fruits and vegetables (2033) and pickles, sauces, and salad dressings (2035). This industry produced 91 percent of the canned specialties; the remainder was produced mainly by Industry 2033, Canned Fruits and Vegetables.

1.012 CANNED FRUITS, VEGETABLES, PRESERVES, JAMS, AND JELLIES – SIC 2033

This industry includes establishments primarily engaged in canning fruits and vegetables, and fruit and vegetable juices; and in manufacturing catsup and similar tomato sauces, preserves, jams, and jellies. Establishments primarily engaged in canning seafoods (except frozen) are classified in Industry 2091; canned specialties, baby foods and soups (except seafood) in Industry 2032.

Production of primary products in 1972 represented 89 percent of the industry's total production. Secondary products produced by this industrial segment consisted mainly of canned specialties (2032) and frozen fruits and vegetables (2037). Production of canned fruits and vegetables by establishments classified in Industry 2033 represented 94 percent of the total; other industries producing these products were mainly 2032, Canned Specialties, and Industry 2037, Frozen Fruits and Vegetables.

1.013 DRIED AND DEHYDRATED FRUITS, VEGETABLES, AND SOUP MIXES – SIC 2034

This classification comprises establishments primarily engaged in sun drying or artificially dehydrating fruits and vegetables, or in manufacturing packaged soup mixes from dehydrated ingredients. Establishments primarily engaged in the grading and marketing of farm dried fruits, such as prunes and raisins, are classified in Industry 5149.

Shipments of dehydrated fruits, vegetables, and soup mixes in 1972 represented 95 percent of the industry's total product shipments. Shipments of these products by other industries were mainly by Industry 2035, Pickles, Sauces, and Salad Dressings, and Industry 2037, Frozen Fruits and Vegetables.

1.014 PICKLED FRUITS AND VEGETABLES, VEGETABLE SAUCES AND SEASONINGS, AND SALAD DRESSINGS – SIC 2035

This industry comprises establishments primarily engaged in pickling and brining fruits and vegetables, and in manufacturing salad dressings, vegetable relishes, sauces, and seasonings. Establishments primarily engaged in manufacturing catsup and similar tomato sauces are classified in Industry 2033, and those packing purchased pickles and olives in trade industries.

Production of pickled fruits and vegetables, sauces, and salad dressings in 1972 represented 80 percent of the industry's total production. Secondary products by this industry consisted mainly of shortening and cooking oils and food preparations not classified elsewhere. Other industries producing these commodities consisted mainly of Industry 2033, Canned Fruits and Vegetables, and Industry 2079, Shortening and Cooking Oils.

1.015 FROZEN FRUITS, FRUIT JUICES, AND VEGETABLES – SIC 2037

This code comprises establishments primarily engaged in freezing and cold packing (freezing) fruits, fruit juices, and vegetables. Prior to 1972 this classification included Frozen Specialties, now assigned a separate industry number, 2038.

Production of frozen fruits, fruit juices, and vegetables in 1972 represented 86 percent of the industry's total production. Secondary products produced by this industry consisted mainly of canned fruits and vegetables, bottled and canned soft drinks, and frozen specialties. Other industries producing frozen fruits, fruit juices, and vegetables consisted mainly of Industry 2033, Canned Fruits and Vegetables, and Industry 2038, Frozen Specialties.

1.016 FROZEN SPECIALTIES – SIC 2038

This new classification comprises establishments primarily engaged in freezing and cold packing (freezing) food specialties, such as frozen dinners and frozen pizza.

Production of frozen specialties in 1972 represented 94 percent of the industry's total production. Secondary products produced by this industry consisted mainly of poultry and egg processing (2017), food preparations not classified elsewhere, and frozen fruits and vegetables. Other industries producing frozen specialties consisted mainly of Industry 2032, Canned

Specialties, Industry 2051, Bread, Cake, and Related Products, and Industry 2037, Frozen Fruits and Vegetables.

1.017 CANNED AND CURED FISH AND SEAFOODS – SIC 2091

This industry comprises establishments primarily engaged in cooking and canning fish, shrimp, oysters, clams, crabs, and other seafoods, including soups; and those engaged in smoking, salting, drying or otherwise curing fish for the trade. Establishments primarily engaged in shucking and packing fresh oysters in non-sealed containers, or in freezing and packaging fresh fish, are classified in Industry 2092.

Production of canned and cured seafoods in 1972 represented 87 percent of the industry's total production. Secondary products produced by this industry consisted mainly of fresh or frozen packaged fish. Other industries shipping canned and cured seafoods consisted mainly of Industry 2032, Canned Specialties.

1.018 FRESH OR FROZEN PACKAGED FISH – SIC 2092

This classification comprises establishments primarily engaged in preparing fresh and raw or cooked frozen packaged fish and other seafood, including soups. This industry also includes establishments primarily engaged in the shucking and packing of fresh oysters in nonsealed containers.

Production of fresh or frozen packaged fish in 1972 represented 96 percent of the industry's total production. The industry's secondary products consisted mainly of canned and cured seafoods. Other industries shipping fresh or frozen packaged fish consisted mainly of Industry 2091, Canned and cured Seafoods.

1.02 Industry Characteristics

1.021 PLANT SIZE

One index of plant size is the total annual production in terms of tons of raw products processed per year. A study by the National Canners Association[1] (NCA), now the National Food Processors Association (NFPA), of SIC 203, excluding 2038, included about 1660 plants processing about 35 million tons of raw products annually. (SIC 2038 was estimated to add another 1 million tons.) The sizes of these plants varied widely, ranging from less than 200 tons per year to more than 700,000 tons. Reported estimates are given in Table 1.04; however, as many as 200 very small facilities may not be represented and would affect these estimates.

TABLE 1.04

PERCENTAGE OF SIC 203 PLANTS BY SIZE

Tons/year (*x1000*)	Percent of plants	Tons/year (*x 1000*)	Percent of plants
.2	12	20	8
.5	14	50	9
1	10	100	5
2	13	200	2
5	12	500 or more	< 1
10	15		

TABLE 1.05

NUMBER OF FOOD PROCESSING ESTABLISHMENTS[1]

Industry Number	North-east	North Central	South	West	Total
2032	47	41	52	63	203
2033	211	299	259	269	1038
2034	20	18	10	130	178
2035	115	150	108	122	495
2037	31	34	45	99	209
2038	110	143	91	91	435
2091	68	15	96	129	308
2092	98	11	287	122	518

1. 1972 Census. Establishments listed by principal activity.

1.022 PLANT AGE

The NCA study indicated a fairly consistent trend of average plant age with plant size: the smallest plants averaged 48 and 45 years old; the largest plants, 27 and 33 years, respectively. Ages were highly variable within size classes. Only 3 percent of the plants in the study were 5 years old or less; 10 percent, 10 years or less; 18 percent, 20 years or less; and 15 percent of the plants were more than 50 years old. The age of equipment within plants was not reported. In another study[2], 60 percent of the food processing plants had had a "major expansion" within a five year period, implying at least some renewal of equipment. In the same study, the older the plant, the less was the distance to the nearest residential development, undoubtedly because of the expansion of cities, towns, and suburbs.

1.023 LOCATION

Food processing plants of the SIC 203 group are located in all of the 48 contiguous states and in Hawaii and Puerto Rico; plants of the SIC 209 group, in the coastal and Great Lakes states, in Hawaii and Alaska, and in Puerto Rico and American Samoa. Thus, plant locations include virtually all climatic zones. The Bureau of Census[3] reports there are over 2500 establishments for SIC 203 and over 800 establishments for SIC 2091 and 2092 (Table 1.05).

With the exception of 2034, Dried and Dehydrated Fruits, Vegetables, and Soup Mixes, the SIC 203 plants are evenly distributed among the four listed regions. However, there are major processing states within each region which in combination account for a large portion of the total number of plants and the total production within each industry category. For SIC 2033, Canned Fruits, Vegetables, Preserves, Jams and Jellies, 70 percent of the establishments are located in twelve states; of the total production, based on value, 16 percent is attributable to the three Mid-Atlantic states, 24 percent to six North Central states, and 31 percent to California. For SIC 2035, Pickles, Sauces, and Salad Dressings, 33 percent of the plants are located in six states (New York, Michigan, Illinois, Texas, Maryland, and North Carolina); these states account for

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[1] National Canners Association. *Liquid Wastes from Processing Fruits, Vegetables and Specialties* (D-2756). NCA, Berkeley, CA. 1974.

[2] Katsuyama, A.M., N.A. Olson, R. L. Quirk, and W. A. Mercer. *Solid Waste Management in the Food Processing Industry* (PB 219 019). National Technical Information Service, US Dept of Commerce, Springfield, VA. 1973.

[3] 1972 Census of Manufactures.

36 percent of the total value of production. For SIC 2037, Frozen Fruits and Vegetables, 41 percent of the establishments are located in the three West Coast states; these facilities produce 32 percent of this industry's output. For SIC 2038, Frozen Specialties, 62 percent of the establishments are located in ten states; 17 percent of the total production value is by the three Mid-Atlantic states, 27 percent by the six North Central states, and 13 percent by California.

By virtue of their products the SIC 209 establishments are concentrated in a few states. For SIC 2091, Canned and Cured Seafoods, 40 percent of the plants are located in five states (Alaska, Maine, California, New York, and Oregon); these states produce 73 percent of the products, based on value, with California accounting for 48 percent of the total for this industry. For SIC 2092, Fresh or Frozen Packaged Fish, 64 percent of the establishments are located in eight states; these states account for 67 percent of the total value of production.

According to the NCA study about two-thirds of the SIC 203 plants (excluding 2038) are situated in urban locations, with a slight tendency for larger plants to be more urban; the locations differed by region, ranging from 37 percent of the North Atlantic plants in urban areas up to 80 percent of the South West plants situated in cities. Many of the processing facilities tend to be locally clustered. According to the study an average of 4.5 plants processing at least some of the same commodities are located within a 30-mile radius; plant clustering varies by region, increasing from 2.4 plants in the East, to 3.9 in the Central region, to 5.5 in the West. However, 31 percent of the plants are unique within the 30-mile radius.

The location of seafood processing plants also varies widely, from isolated facilities in the remote areas of Alaska to clusters of plants in the large coastal metropolitan regions.

1.024 SEASONALITY

Most of the SIC 203 plants are seasonal, operating when their raw products are available. (Citrus, potatoes, and specialty plants tend toward year-around operation.) During the remainder of the year these plants may close or process repacked specialties, dry beans, or other non-seasonal items. The NCA study indicated that plants operated during 7.8 months of the year on average. The "major operating season," defined as the span of months during which a plant processed 75 percent of its total annual tonnage, averaged 4.2 months. The largest plants had longer than average total and major operating seasons; the smallest, longer than average total but not major seasons. However, the seasons varied widely within size classes. Average seasons differed among regions as listed in Table 1.06.

TABLE 1.06
REGIONAL SEASONALITY OF SIC 203 PLANTS

Region	Total Season (*months*)	Major Season (*months*)
East	9.0	4.8
Central	7.1	4.0
West	7.3	4.0
Total	7.8	4.2

The SIC 2091 plants operate from as little as ten days per year (Alaska salmon) to the year-around (California tuna); however, most have operating seasons of several months. The SIC 2092 plants are also seasonal and depend entirely on the species of fish that are locally available; most plants receive several species, thereby extending their operating season from several months to the year-around.

1.1

WATER POLLUTION

Water is composed of one hydrogen ion (H^+) and one hydroxyl group (OH^-) and is chemically expressed as H_2O. In its pure state water contains no other matter. Therefore, any material added in either a dissolved or suspended state may theoretically be considered a pollutant.

In its natural state, however, water does contain a wide variety of substances, such as dissolved minerals, atmospheric gases, and aquatic flora and fauna. Thus, the term "pollutant" is generally reserved for matter that is introduced into water by man, or as a result of his activities, in concentrations which seriously affect the natural or "pristine" state of the aquatic environment.

The natural state of the aquatic environment is a complex one. Numerous factors affect water quality and, in turn, the ecology of any body of water. Foremost among these are climate, precipitation, geology and topography. These factors determine such critical water conditions as temperature, rate of flow, mineral and nutrient content, and depths and sizes of water bodies. These conditions in turn dictate the types and numbers of aquatic flora and fauna which can exist within each stream or lake.

Man's activities have influenced many, if not all, of the natural conditions in many streams and lakes. Dams have been constructed, thereby reducing flows downstream while creating large bodies of water upstream. Water has been diverted from rivers for domestic, industrial and agricultural purposes and returned as wastewater with different characteristics. Wastes of all types have been discharged into streams and lakes, also changing the natural composition of the water and frequently affecting its normal temperature. It is the repeated and often continuous impacts of these activities which have resulted in the decreasing availability of clean water. Therefore, these activities are now the target of environmental regulations designed to curb pollution and to improve the quality of our surface waters.

1.11 Water Quality Regulations

Federal legislation directed toward curbing water pollution is based on the principle that no one has the right to pollute the nation's waters. To restore the chemical, physical, and bacteriological integrity of all waters, the Federal Water Pollution Control Act establishes two systems for controlling discharges of pollutants into surface waters. The first system is oriented toward maintaining specified minimum water qualities in each stream or lake; the second is directed toward regulating the quantity of pollutants discharged from each source.

1.111 WATER QUALITY STANDARDS

Each state is required to establish water quality standards by classifying each stream, or stretch of stream, within its jurisdiction according to designated uses. Approved uses include: recreation – primary contact (swimming, water skiing, skin diving) and secondary contact (fishing, wading, boating); propagation of fish (warm and cold water), shellfish, and wildlife; public water supplies; agriculture; industry; and navigation. The standards must set forth water quality criteria – that is, minimum physical, chemical, and bacteriological parameters – necessary to support each designated use. Each state must also adopt an antidegradation policy as part of its water quality standards to prohibit deterioration of waters where existing quality is higher than established standards.

The water quality standards affect all wastewater discharges to the extent that such discharges must not impair the designated use of the receiving water by reducing the water quality below the specified minimum criteria. The reader should consult the appropriate regulatory agency for quality standards established for water in his locale. Water quality parameters of significance to the food processing industry are discussed in Section 1.12.

1.112 EFFLUENT LIMITATIONS

The Federal Water Pollution Control Act Amendments of 1972, PL 92-500, established as a "national goal that the discharge of pollutants into the navigable waters be eliminated by 1985." Since navigable waters has been defined to include all tributaries to waters capable of bearing commercial traffic. all streams are affected by the legislation. As a means of working toward achieving the "zero discharge" goal, the Environmental Protection Agency has been directed to establish a schedule of effluent limits based on the application of progressively advanced treatment technology. These limits are to be established for each major industry group (Table 1.07).

TABLE 1.07
LIST OF CATEGORIES OF WASTEWATER SOURCES FOR WHICH EFFLUENT LIMITATIONS ARE TO BE ESTABLISHED[1]

- Pulp and paper mills
- Paper board, builders paper and board mills
- Meat product and rendering processing
- Dairy product processing
- Grain mills
- Canned and preserved fruits and vegetable processing
- Canned and preserved seafood processing
- Sugar processing
- Cement manufacturing
- Feedlots
- Organic chemicals manufacturing
- Inorganic chemicals manufacturing
- Plastic and synthetic materials manufacturing
- Soap and detergent manufacturing
- Fertilizer manufacturing
- Petroleum refining
- Iron and steel manufacturing
- Nonferrous metal manufacturing
- Phosphate manufacturing
- Steam electric power plants
- Ferroalloy manufacturing
- Leather tanning and finishing
- Glass and asbestos manufacturing
- Rubber processing
- Timber products processing

1. Federal Water Pollution Control Act, §306(b)(1)(A).

The Act initially required that effluent limits for existing point sources reflect the application of (1) "the best practicable control technology currently available" (BPT) by July 1, 1977, and (2) "the best available technology economically achievable" (BAT) by July 1, 1983. Performance standards for all new sources must be based on the "best available demonstrated technology." However, the Clean Water Act of 1977, PL 95-217, which further amended the Federal Water Pollution Control Act, significantly altered the BAT requirements.

The Clean Water Act requires EPA to establish a "conventional pollutant" category. This category is to include, but is not limited to, pollutants classified as biochemical oxygen demand (BOD), suspended solids (TSS), fecal coliform, and pH. The EPA is further required to establish effluent limitations reflecting the application of the "best conventional pollutant control technology" (BCT) for classes and categories of point sources other than publicly owned treatment works. In establishing these regulations, EPA must consider the reasonableness of the relationship between the cost of obtaining a reduction in pollutants and the benefits to be derived therefrom.

Industrial dischargers of conventional pollutants will no longer be required to implement BAT. Instead, dischargers of conventional pollutants, which will likely include most food processing plants, much achieve by no later than July 1, 1984, effluent limitations reflecting the application of BCT. Since the costs of achieving these limitations are to be considered prior to promulgation, only those dischargers who can demonstrate the existence of significantly different circumstances from factors considered by EPA will be able to seek relief from BCT regulations.

All pollutants not specifically designated as "conventional," "toxic," or "thermal" are to be categorized as "nonconventional." Dischargers of nonconventional pollutants must achieve effluent limitations reflecting the application of BAT by no later than July 1, 1987. However, applications for economic- or water quality-based waivers may be submitted to the permit-issuing agency within 270 days of the promulgation of effluent guidelines and standards.

A list of toxic pollutants (see Section 1.126) is to be published and periodically revised by the EPA. Effluent limitations reflecting BAT are to be promulgated for each by July 1, 1980. Dischargers of such pollutants must comply with the promulgated limitations by July 1, 1984. Effluent standards or prohibitions may also be established for some of these substances. Dischargers of these must comply with the more stringent requirements within one year of their promulgation. No waivers may be granted for BAT effluent limitations or effluent standards for toxic pollutants.

Food processing plants generally will be required to provide secondary treatment as the best practicable control technology. Higher quality treated effluents may be required to meet water quality standards. Higher quality effluents are purportedly achievable through in-plant waste load reductions, increased efficiencies of secondary treatment systems, and advanced wastewater treatment when necessary. New plants may be required to implement all of the latter measures or conform to modified requirements which the applicant can show "(1) will represent the maximum use of technology within the economic capability of the owner or operator, and (2) will result in reasonable further progress toward the elimination of the discharge of pollutants."[1]

1.12 Water Quality Parameters

The impact which discharged pollutants have on receiving waters is evaluated by measuring certain water quality parameters. These measurements are made by analyzing samples collected from the wastewater or from the receiving stream after mixing has occurred. The parameters of primary concern to food processors are discussed below.

1.121 DISSOLVED OXYGEN

A stream normally possesses the ability to purify itself. Water flowing in a stream becomes aerated (oxygen enriched) as it tumbles over rocks and other natural obstacles. The dissolved oxygen in turn enables the water to sustain a variety of oxygen-dependent microorganisms, as well as other aquatic life. These microorganisms are primarily responsible for the stream's self-purifying capability. When plant debris and other waste materials are deposited into water, the microorganisms

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[1] Federal Water Pollution Control Act, Section 301(c).

quickly utilize these materials, ultimately converting the organic matter to cell mass and carbon dioxide. Dissolved oxygen in the water is consumed during the biological process.

The rate at which dissolved oxygen is consumed is directly related to the concentration of pollutants present in water. That is, the higher the concentration, the more active are the bacteria, and hence the higher the rate at which oxygen is used; the lower the concentration, the lower the consumptive or deoxygenation rate. When the consumptive rate exceeds the oxygenation rate of a stream, the level of dissolved oxygen in the water begins to decrease. Since minimum levels of dissolved oxygen are required by fish and other aquatic life, excessive oxygen depletion will result in biological stress and, ultimately, fatality. The quantity of pollutants which may be added to a stream without deleterious effects on aquatic organisms is called the assimilative capacity of the stream.

Waste discharges, whether domestic sewage or industrial wastewaters, impose demands upon the assimilative capacity of the receiving water. When a heavy load exceeding the assimilative capacity is discharged, the dissolved oxygen content of the stream will be greatly depressed. However, provided no further waste discharges occur downstream, the dissolved oxygen content of the stream will eventually be reestablished. A graph depciting the profile of the dissolved oxygen content in such a situation is called an oxygen-sag curve (Figure 1.02). Excessive waste loads can result in the complete depletion of dissolved oxygen. In such an event the water will no longer support most aquatic life. Instead, microorganisms capable of existing without oxygen will begin to predominate and eventually exist exclusively. These so-called anaerobic organisms can only partially stabilize organic matter, giving rise while so doing to the odorous gases which are commonly associated with stagnant ponds and septic tanks.

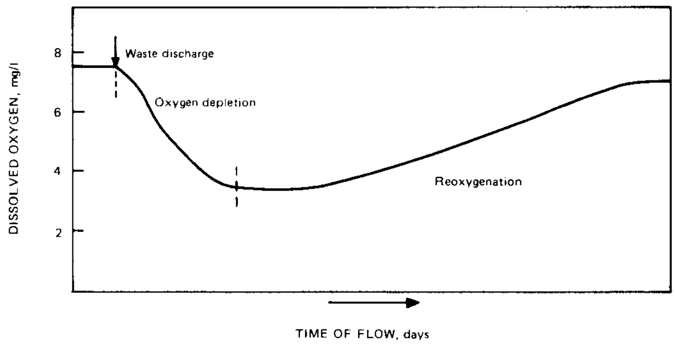

Figure 1.02. A hypothetical oxygen-sag curve.

Although dissolved oxygen is generally not a significant parameter when dealing exclusively with waste streams, it is of vital concern in receivng waters, as indicated above; a minimum of 5 mg/l is considered to be desirable for sustaining game fish (trout, salmon, etc.). Control of dissolved oxygen concentrations is also important in biological treatment systems which utilize the same principle responsible for a stream's self-purification capability – that is, reliance on aerobic bacteria to stabilize organic matter; a minimum of 0.5 to 1.0 mg/l must be maintained within such systems for maximum efficiency and avoidance of objectionable odors.

1.122 TEMPERATURE

The solubility of oxygen in water is inversely proportional to temperature, as illustrated in Figure 1.03. The temperature of water also affects aquatic organisms – some species can only survive in relatively cool waters while others require a warmer environment. The level of microbiological activity is also affected by temperature. Thus, temperature is considered to be an important parameter.

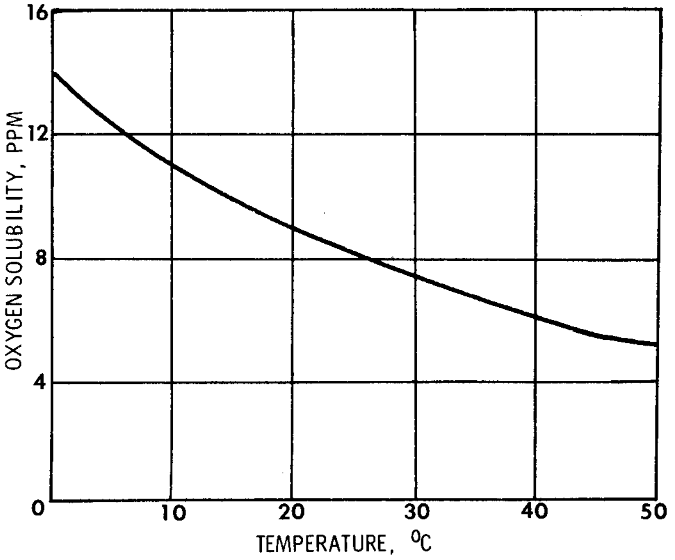

Figure 1.03. Solubility of oxygen in water (assuming air with 20.9% O_2 at 760 mm Hg Pressure).[1]

However, the temperature of wastewater discharged to receiving streams is of concern only from the standpoint of its effect on the temperature of the receiving water (thermal pollution). Therefore, temperature requirements are usually based upon the receiving water temperature. Generally, the normal water temperature must not be raised more than 5 F^{O}. Temperature measurements are taken beyond a minimal area generally allowed for mixing.

When retort or condenser water are released into streams with low flow, cooling towers or ponds may be required to cool the heated wastewater to an acceptable temperature. These waters generally do not require further treatment and should be separately handled from other processing wastewaters.

1.123 OXYGEN DEMAND

Oxygen demand is defined as that quantity of oxygen required to degrade, and thereby stabilize, the organic constituents of wastewaters. Under natural conditions in receiving streams the oxygen source is the dissolved oxygen contained in the water. To measure the pollutional strength of wastewater in terms of effects upon the dissolved oxygen content in receiving waters, several laboratory tests are routinely used.

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1. From: Gurnham, C. F. *Principles of Industrial Waste Treatment.* John Wiley & Sons, Inc., New York (1955).

1.1231 Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) test has been devised to simulate under laboratory conditions the biochemical reactions which occur in receiving streams. The procedures for this test are described in Section 3.513. Factors, such as time, temperature, pH, and dissolved oxygen content, are standardized, thereby enabling direct comparisons of relative pollutional strengths of various wastewater samples.

The normally-used BOD test procedure requires a five-day sample incubation period; the results are reported as five-day BOD, or BOD_5. It is assumed that during this period most carbonaceous and other readily oxidizable materials have been biochemically degraded. Other waste constituents, especially nitrogenous compounds, are degraded more slowly; only a portion of these materials are measured during the five-day test. For this reason, BOD determinations are sometimes made after a twenty-day incubation period and are reported as 20-day BOD (BOD_{20}). Ultimate BOD determinations require prolonged incubation periods and are generally only of academic interest. A typical BOD rate curve is illustrated in Figure 1.04. Unless otherwise stated, reported BOD values are always five-day BOD.

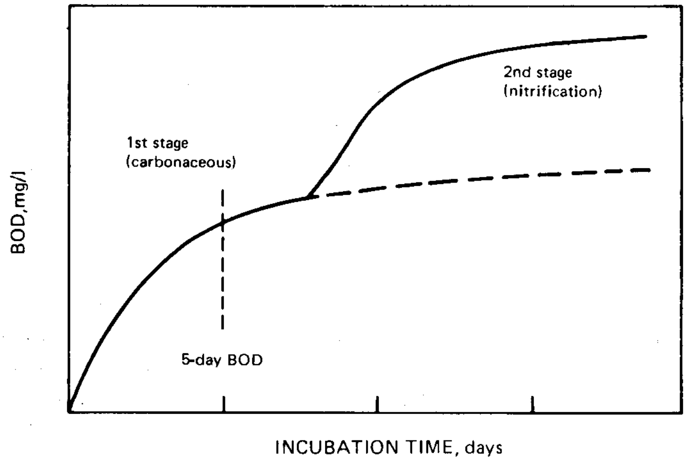

Figure 1.04. A typical BOD reaction curve for untreated wastewater.

Analytical results from the BOD test are expressed as milligrams per liter (mg/l) – i.e., the milligrams of dissolved oxygen consumed under test conditions per liter of wastewater. Organic loads contained in industrial effluents are frequently expressed as pounds of BOD. Laboratory data (mg/l) may be converted to organic loads (lbs) by the following equation:

$$\text{pounds BOD} = \frac{C \times V \times 8.34}{1{,}000{,}000}$$

where C = concentration (mg/l or ppm BOD)
V = volume of wastewater (gallons)
8.34 = weight, in pounds, of one gallon of water

The BOD of most wastewaters are attributable to organic matter present in the water in two forms, solid and dissolved. Therefore, it is possible to obtain two distinct BOD values for most wastes. Total BOD, obtained by analyzing a blended or homogenized sample, is of primary interest when determining the oxygen demand of wastewaters which are discharged directly into a receiving stream or to a treatment system. The soluble BOD, obtained by removing solid matter by settling or filtering the sample, is of primary interest when contemplating pretreatment of wastewaters prior to discharge. For most fruit and vegetable processing wastewaters which have been screened, the soluble BOD will be greater than 85% of the total BOD.

1.1232 Chemical Oxygen Demand

The relative pollutional strength of wastewaters is often measured by the chemical oxygen demand (COD) test. Two procedures for the test are described in Section 3.514. The oxygen demand as measured by this test is based upon chemical reactions between the constituents in the wastewater and the test reagents, as compared to biochemical reactions which are measured by BOD analysis. Because some wastewater constituents are not biologically degradable but can be chemically oxidized, COD values are higher than BOD values. However, the relative rapidity – two hours vs. five days – of the COD test makes it useful for routinely monitoring wastewater discharges. Correlation factors between COD and BOD can generally be established for each individual waste stream. COD test results are expressed as milligrams per liter (mg/l); the preceding equation may be used to convert concentrations to pounds of COD.

1.1233 Total Oxygen Demand and Total Organic Carbon

Laboratory equipment has been developed to instrumentally measure the relative pollutional strength of wastewater samples. Wastewater samples introduced into these automated apparatus are combusted in a furnace. In the total oxygen demand (TOD) analyzer the quantity of oxygen consumed during combustion is quantitatively measured; in the total organic carbon (TOC) analyzer, the quantity of carbon dioxide which is generated during combustion is quantitatively measured. Results are obtained within minutes, thereby rendering either instrumental method valuable for process control, as well as for routine monitoring programs. Correlation factors between either TOD or TOC and BOD and/or COD can generally be established for specific wastes.

1.124 SUSPENDED SOLIDS

In laboratory determinations all inorganic and organic particulate matter which are removed by standard filtration procedures are reported as suspended solids (SS) or nonfilterable matter (see Section 3.519). Food processing wastewaters are generally screened prior to discharge; this practice is effective in removing large particles of product and debris. However, raw food processing wastewaters contain large quantities of small organic particles, as well as soil and silt from washing operations, which are measured as suspended solids. Effluents from biological treatment systems can also contain significant quantities of suspended matter; these generally consist of clumps of biomass (microorganisms) which are present within the system.

Suspended solids in wastewaters are considered to be an important parameter for several reasons:

1. Nonfilterable organic matter (suspended solids) can form floating scum blankets on the surface of treatment ponds and lagoons, as well as in receiving waters. The presence of scum is not only aesthetically unacceptable, but also detrimentally affects the effi-

ciency of treatment by reducing oxygen transferability from the air to water and by preventing the penetration of light into the water. Furthermore, scum blankets may attract flies and provide breeding harborages, thereby creating public health problems.

2. Nonfilterable matter with specific gravities close to that of water will remain in suspension. Such materials can create turbid conditions in water and may impart a distinct color. Both situations are aesthetically undesirable. Turbidity will also reduce light penetration and thereby affect aquatic life.
3. Heavy suspended solids will tend to settle in ponds or in slow-flowing streams, thus forming sludge deposits. When these deposits contain a high concentration of organic matter, degradation of the organics will occur anaerobically. The consequent production of odorous gases will frequently cause clumps of sludge material to rise to the surface, resulting in the release of objectionable odors. Sludge deposits are not only unaesthetic, but can seriously impair both the quality of water and the efficiency of a treatment system.

Suspended solids include a wide variety of matter – large and minute particles, organic and inorganic matter, floatable and settleable materials. Treatment procedures to reduce the suspended solids concentration in wastewaters vary accordingly; several methods are described in Section 4. Laboratory results of suspended solids analysis are expressed in milligrams per liter (mg/l); the equation given in the BOD discussion may be used to determine the organic load (lbs) associated with nonfilterable matter.

1.125 FLOW

The quantity of water used in food processing plants, and hence the volume of wastewater discharged from each facility, varies widely; the sources and quantities, as well as factors that influence waste generation, are discussed later in this section. The highly-variable nature of food processing plants makes each facility somewhat unique from others within the industry relative to wastewater discharges.

Accurate flow measurements are essential for determining the hydraulic load and for calculating the organic load of wastewater discharges. Each processing plant must provide suitable means for measuring and recording the volume of its effluent (see Section 3.3). This information is required to properly design wastewater treatment facilities and to evaluate the effectiveness of in-plant pollution abatement measures. Plants discharging wastewaters into publicly-owned treatment works will be assessed sewer service charges based on both hydraulic and organic loads.

1.126 TOXIC COMPOUNDS

The Federal Water Pollution Control Act defines "toxic pollutants" as:

> . . . those pollutants, or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will . . . cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring.[1]

A list of toxic pollutants (Table 1.08) has been published by the U.S. Environmental Protection Agency; the list will be updated as information becomes available.

Of the toxic compounds currently listed, only the various pesticides may be of concern to the food processing industry. Since the use of pesticides on food crops is closely regulated, there is little or no residue on produce delivered to food processing plants. Therefore, toxic pollutants are generally absent from food processing wastewaters.

1.127 OTHER PARAMETERS

The major parameters for food processing wastewaters are flow, biochemical oxygen demand (BOD), and suspended solids (SS). Other parameters may be of concern depending upon the nature of the operations conducted at the facility and the method of wastewater disposal from the site. In addition to those described above, other wastewater parameters of common concern are described below.

1.1271 pH

pH is a measure of the hydrogen ion concentration [H^+] in a solution and indicates the acidic or basic character of a substance. pH values are expressed by a numerical scale from 0 to 14 – the 0 to 7 range is the acid scale, the 7 to 14 range is the alkaline scale, and the mid-point, 7.0, is neutral. Accurate measurements can be made only with a suitable pH meter (see Section 3.501); however, estimates can be obtained by using appropriate indicator strips (pH paper). Although pH measurement determine the relative acidity or basicity of a substance, pH values alone will not indicate its buffering capacity, i.e., its capacity to accept acid or alkali without corresponding changes in the hydrogen ion concentration.

The pH of food processing wastewaters may vary from 3.5 to 11.5, depending upon the product being packed and the types of operations conducted within the plant. High acid foods (fruits) and acidified or fermented products (pickles, sauerkraut) may produce effluents with low pH values; low acid foods (vegetables, seafoods, meats) will generate slightly acid wastewaters with pH values between 5 and 7; caustic-utilizing operations will result in alkaline wastewaters as high as pH 11.5 or more.

Natural-occurring waters have pH values between 5.5 and 8.5; effluent limits frequently state that wastewater discharges must be between pH 6.5 and 8.5. Aquatic organisms are extremely sensitive to pH values outside of this range. Therefore, accurate pH measurements and control of plant effluents are often essential for successful treatment and disposal.

1.1272 Acidity and Alkalinity

When an effluent has either a low or a high pH, neutralization may be required before it can be treated or discharged. Many substances have a buffering capacity, as previously

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[1] Federal Water Pollution Control Act. §502(13).

TABLE 1.08
LIST OF TOXIC POLLUTANTS[1]

1. Acenaphthlene.
2. Acrolein.
3. Acrylonitrile.
4. Aldrin/Dieldrin.[2]
5. Antimony and compounds.[3]
6. Arsenic and compounds.
7. Asbestos.
8. Benzene.
9. Benzidine.[2]
10. Beryllium and compounds.
11. Cadmium and compounds.
12. Carbon tetrachloride,
13. Chlordane (technical mixture and metabolites).
14. Chlorinated benzenes (other than dichlorobenzenes).
15. Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane, and hexachloroethane).
16. Chloroalkyl ethers (chloromethyl, chloroethyl, and mixed ethers).
17. Chlorinated naphthalene.
18. Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols).
19. Chloroform.
20. 2-chlorophenol.
21. Chromium and compounds.
22. Copper and compounds.
23. Cyanides.
24. DDT and metabolites.[2]
25. Dichlorobenzenes (1,2-, 1,3-, and 1,4-dichlorobenzenes).
26. Dichlorobenzidine.
27. Dichloroethylenes (1,1-, and 1,2-dichloroethylene).
28. 2,4-dichlorophenol.
29. Dichloropropane and dichloropropene.
30. 2,4-dimethylphenol.
31. Dinitrotoluene.
32. Diphenylhydrazine.
33. Endosulfan and metabolites.
34. Endrin and metabolites.[2]
35. Ethylbenzene.
36. Fluoroanthene.
37. Haloethers (other than those elsewhere; includes chlorophenylphenyl ethers, bromophenylphenyl ether, bis-(dichloroisopropyl) ether, bis-(chloroethoxy) methane, and polychlorinated diphenyl ethers).
38. Halomethanes (other than those listed elsewhere; includes methylene chloride, methylchloride, methylbromide, bromoform, dichlorobromomethane, trichlorofluoromethane, dichlorodifluoromethane).
39. Heptachlor and metabolites.
40. Hexachlorobutadiene.
41. Hexachlorocyclohexane (all isomers).
42. Hexachlorocyclopentadiene.
43. Isophorone.
44. Lead and compounds.
45. Mercury and compounds.
46. Naphthalene.
47. Nickel and compounds.
48. Nitrobenzene.
49. Nitrophenols (including 2,4-dinitrophenol, dinitrocresol).
50. Nitrosamines.
51. Pentachlorophenol.
52. Phenol.
53. Phthalate esters.
54. Polychlorinated biphenyls (PCBs).[2]
55. Polynuclear aromatic hydrocarbons (including benzanthracenes, benzopyrenes, benzofluoroanthene, chrysenes, dibenzanthracenes, and indenopyrenes).
56. Selenium and compounds.
57. Silver and compounds.
58. 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).
59. Tetrachloroethylene.
60. Thallium and compounds.
61. Toluene.
62. Toxaphene.[2]
62. Trichloroethylene.
64. Vinyl chloride.
65. Zinc and compounds.

[1] Federal Register, Vol. 43, No. 21, p. 4109. (January 31, 1978)
[2] Effluent standard promulgated (40 CFR Part 129).
[3] The term "compounds" shall include organic and inorganic compounds.

mentioned. pH measurements alone will not indicate the quantity of acid or alkali required to neutralize these substances. Instead, the acidity of low pH wastewaters or the alkalinity of high pH wastes must be determined. The required quantity of lime, commonly used to raise the pH of water, can be determined for acid wastes as described in Section 3.5022; the quantity of acid required to neutralize alkaline wastes can be calculated as described in Section 3.5032.

1.1273 Oil and Grease

Oil will form a film on the surface of water; the film is readily detected by its iridescence even when extremely thin. Grease can agglomerate and form unsightly scum blankets. Oil and grease may be of concern to specialty product, seafood, and meat processing plants. Discharge permits often impose limits on the quantity of oil and grease allowed in wastewaters discharged to receiving streams. The laboratory analysis[1,2] utilizes a solvent extraction procedure. Suitable treatment methods to remove oil/grease are described in Section 4.115.

1.1274 Chloride (salt)

Chloride, or more generally salt (Nacl – see Section 3.505), in fruit and vegetable processing effluents are associated with brining operations. Brines from quality graders and fillers are usually diluted by sufficient volumes of processing wastewaters such that the final concentration is adequately low.

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[1] American Public Health Association. *Standard Methods for the Examination of Water and Wastewater* (14th edition). APHA, Washington, D.C. (1976) pp 513-521.

[2] U.S. Environmental Protection Agency. *Methods for Chemical Analysis of Water and Wastes.* EPA-Office of Technology Transfer, Washington, D.C. (1974) pp 226-235.

However, the disposition of large volumes of high-saline brines, such as those associated with olive, sauerkraut, and pickle processing, is frequently a problem.

Saline waters cause metal corrosion and are toxic to freshwater fauna and flora. Salt will impair the quality of receiving waters and in high concentrations will exert deleterious effects on agricultural crops. The sodium ion in table salt can react with clay soils, resulting in drastic decreases of water and air permeability through such soils. For these reasons extreme care must be exercised in the management of saline wastewaters. Stringent limits for chloride/salt are frequently imposed on discharges from brining facilities.

1.1275 Nutrients

Aside from carbonaceous organic matter (which is largely measured as BOD), the nutrients of primary concern are nitrogen- and phosphorus-containing compounds (see Sections 3.510 and 3.515, respectively). Both are required by microorganisms for reproduction and are largely responsibe for "algal blooms" which periodically occur in streams and lakes.

To optimize efficiencies of biological wastewater treatment systems, nitrogen (N) and phosphorus (P) concentrations are adjusted according to the BOD concentration in the wastewater. The generally recommended ratio of BOD to total N to total P is 100:5:1. Fruit and vegetable processing wastewaters are nutrient deficient and normally require the addition of nitrogen compounds for effective biological treatment; wastewaters from meat and seafood processing have excess nitrogen and may require (rarely) nitrogen removal prior to discharge. Detergents used for product washing and plant cleanup usually provide a source of sufficient water-soluble phosphates to satisfy the needs of microorganisms in biological treatment systems; however, injudicious use of cleaning chemicals may result in the discharge of excess phosphorus. Although limits on N and P are imposed only infrequently on food processing discharges, their discharged concentrations must be minimized by closely controlling the use of source chemicals.

1.2

SOURCES, VOLUMES, AND CHARACTERISTICS OF FOOD PROCESSING WASTES

The quantities of fresh water used by a food processor and the volumes and characteristics of wastewater that result are highly variable. Many of the factors which contribute to variability are discussed in the following; the major factors are described in more detail in Section 1.3.

The values quoted in this section are averages (with ranges and statistical significance where available) that have been reported in the literature or that have been established by industry surveys. By no means are these to be considered "typical" for their associated categories. Rather, the data substantiate the variable nature of processing effluents and the need to develop pertinent information for each processing facility. However, the provided information illustrates the relative characteristics between categories. The reported values may be useful as a general guide in determining how each facility compares to the industry situation in a particular category.

1.21 Water Usage

The volume of water used to process a ton of raw product varies widely, not only between commodities, but also within each commodity group. Information elicited during an industry survey[1] is summarized in Table 1.09; the listed values are averages with wide ranges.

Initial consideration should be given to the "gross applied water" volumes. These are the volumes of fresh water that would be used to process each of the listed commodities if water is used once and then discarded. However, water in most fruit and vegetable processing plants is conserved by reusing it among operations and by recirculating it within operations, as indicated in the table. Thus, the volume of "fresh intake water" and the volume of "discharged water" are both generally less than the total volume of water required by the processing operations. (The only exceptions are for concentrated products where water is extracted from the raw product.)

Fresh water is used primarily for steam generation, blanching, product cooling, final product washing, freezing or container cooling, plant cleanup (sanitation), and for numerous other minor purposes. Water may be recirculated within dump tanks, flood washers, hydraulic transport systems, and cooling systems with cooling towers. Clean water discharged from operations in the late stages of processing may be reused in earlier operations. Measures by which fresh water requirements can be minimized are discussed in Section 2, Waste Prevention and Reduction.

Knowledge of the quantities of fresh water used and the volumes of resultant wastewater are vital to the waste management program at each facility. Procedures for obtaining this information are described in Section 3, Monitoring Liquid Waste Flows.

1.22 Liquid Wastes (Wastewaters) From Food Processing Operations

1.221 WASTEWATER GENERATION

Fresh water used in numerous food processing operations dissolves organic matter from the raw commodities and becomes a carrier of a variety of undissolved or suspended materials which are ultimately discharged as processing wastewater. The potential impact of wastewater discharges, either upon a receiving stream or a treatment system, can best be evaluated by accumulating specific information with which to determine the "waste load" associated with the discharge. Waste loads are used by engineers to design appropriate waste-

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[1] National Canners Association. Liquid Wastes from Processing Fruits, Vegetables and Specialties (D-2756). National Canners Association, Berkeley, CA. 1974.

TABLE 1.09
WATER USED IN PROCESSING FRUITS AND VEGETABLES

Commodity	Style	Water Used (1) F	R (1000 gal/ton)	G	D	(2) %
apple	slice, dice rings	3.4	.5	3.9	3.2	13
"	sauce	2.1	.9	3.0	2.1	30
"	juice	2.4	1.0	3.4	2.3	29
apricot	unpeeled	6.1	6.7	12.8	6.3	52
"	peeled	7.6	6.7	14.3	8.9	47
asparagus	all	5.1	3.3	8.4	6.2	39
dry bean, pea	all	7.8	1.9	9.7	7.3	20
snap bean	whole freeze	3.7	2.9	6.6	3.6	44
"	cut freeze	3.7	2.9	6.6	3.6	44
"	slice freeze	5.5	3.5	9.0	5.4	39
"	whole can	4.3	3.6	7.9	4.0	46
"	cut can	4.4	3.3	7.7	4.1	43
"	slice can	5.4	3.4	8.9	5.2	38
beet	whole, quarter	1.9	1.5	3.4	1.9	44
"	slice cut	1.9	1.5	3.4	1.9	44
carrot	slice freeze	8.1	2.4	10.5	8.0	23
"	dice freeze	6.6	2.7	9.3	6.5	29
"	slice can	3.1	6.0	9.1	2.8	66
"	dice can	3.0	5.7	8.7	2.8	66
cherry	whole	4.2	1.9	6.2	4.2	31
"	pitted	5.6	1.4	7.0	5.5	20
citrus (3)	concentr. freeze	2.5	.1	2.6	3.6	4
"	ss juice can	3.0	.2	3.2	2.6	5
corn	wh. kernel freeze	3.9	3.5	7.5	3.7	47
"	cob freeze	4.4	1.4	5.7	2.4	25
"	wh. kernel can	4.9	1.4	6.3	4.5	23
"	cream st. can	2.9	1.8	4.7	2.4	38
lima	whole	8.5	2.6	11.1	8.3	24
okra	whole	5.7	.1	5.8	5.6	2
"	cut	6.2	.1	6.3	6.1	2
pea	whole freeze	3.9	4.9	8.8	3.8	56
"	whole can	4.2	5.7	9.9	4.0	58
peach	whole	4.2	9.1	13.3	4.8	68
"	half	3.3	7.3	10.7	3.3	68
"	slice	4.0	6.9	10.9	4.1	63
"	dice	3.8	6.5	10.3	4.1	63
pear	half	3.9	5.2	9.1	4.0	58
"	slice dice	3.8	5.9	9.7	4.1	61
peppers	dice, slice, cut	8.6	2.2	10.7	8.7	21
white potato	whole freeze	4.9	3.9	8.8	5.9	44
"	fries freeze	2.9	17.7	20.9	3.1	85
"	whole can	5.6	1.6	7.2	5.7	22
"	slice, dice freeze, can	4.4	2.9	7.4	5.3	39
pumpkin squash	all	3.8	2.4	6.2	3.5	39
sweet potato	whole	3.6	.5	4.0	3.5	12
"	dice slice	3.9	.4	4.3	3.8	9
sauer-kraut	preparation only	1.1	0	1.1	1.1	0
"	can only	1.1	.5	1.6	1.0	31
spinach greens	whole freeze	8.5	.5	9.0	8.5	6
"	chopped freeze	6.2	.5	6.7	6.2	7
"	whole can	10.0	3.2	13.2	9.6	24
"	chopped can	9.8	3.4	13.2	9.3	26
tomato	peeled	3.4	9.5	12.7	3.5	75
"	juice	1.5	3.4	4.9	1.3	69
" (4)	concentr. products	1.5	6.0	7.7	1.8	78

Notes:

1. Water used: F = fresh intake water; R = water reused (among operations) and recirculated (within operations); G = gross applied water (=F+R); D = discharged water.
2. Percent of water reused or recirculated: (R/G)100.
3. Citrus concentrate: also 1.7, 0, 1.7, 2.4 for evaporation.
4. Concentrated tomato products: also 0.5, 1.5, 2.0, 0.6 for evaporation.

water treatment facilities, by regulatory authorities to specify effluent limitations, and by municipalities to levy surcharges for sewer services.

1.2211 Raw Waste Loads

There are two aspects of industrial waste loads which are of primary concern. The first is the volume or quantity of wastewater which must be treated or disposed. This is referred to as the *hydraulic load.* The second consideration is the pollutional strength of the wastewater, that is, the quantity of pollutants contained in the discharge. This is evaluated in terms of specific water quality or wastewater parameters, as discussed earlier (Section 1.12). For most food processing wastes the parameters of major concern are biochemical oxygen demand (BOD) and suspended solids (SS). These are collectively referred to as the *organic load.* The hydraulic and organic loads comprise what is called the *raw waste load (RWL).*

Wastewater characteristics from several fruit and vegetable commodities are listed in Table 1.10; the values represent the

TABLE 1.10

WASTEWATER AND GENERATED POLLUTION LOADS BY COMMODITY – FRUITS AND VEGETABLES

	Wastewater 1000 gallons/ton			BOD pounds/ton			SS pounds/ton			Temp.	pH
	ave	95% limits		ave	95% limits		ave	95% limits		ave	ave
apple	3.2	.2	17	22	4.4	64	6.3	.5	30	54	5.6
apricot	4.9	1.1	14	45	17	98	9.9	4.0	22	76	8.0
asparagus	8.6	1.4	31	5	.6	26	7.5	4	13		
dry bean	9.8	1.1	44	75	16	238	59	(2	130)*		6.8
snap bean	4.7	1.1	14	20	.7	116	7.0	.3	63	70	7.3
beet	4.0	.8	12	44	5	217	26	2	116		7.9
berry	3.5	.4	16	24	5.2	77	16	(1	57)*		
broccoli	8.8	1.6	32	16	2.1	54					
cauliflower	11	(1.7	23)*	18	(2	49)*					
carrot	4.0	.8	13	31	9.6	80	17	2.0	72	63	8.7
cherry	4.8	.4	27	15	2.4	75	.8	(.5	1)*		
citrus	4.3	.4	16	16	(1	45)*	6.0	(2	10)*	79	6.5
corn	1.9	.3	6.2	27	4.8	91	12	2.1	44	77	5.6
grape	2.8	.3	13								
lima	7.3	1.4	24	58	6.0	240	50	2.7	332		
mushroom	9.6	1.7	33	20	8.8	40	10	4.2	22		
okra	5.0	1.3	15								
onion	6.8	(.2	17)*								
pea	4.7	1.2	13	38	13	88	12	1.3	67	70	6.0
peach	3.0	1.1	6.8	45	13	116	9.1	1.8	30	72	9.6
pear	3.9	1.5	8.4	44	8.6	147	8.7	1.7	29		7.0
peppers	4.6	.9	16	32	(5	50)*	58	(1	170)*		
pickle	4.6	.8	19								
pineapple	1.7			16	7.4	31	9.9	3.5	24	92	6.8
plum	4.9	.4	23	11	(3	19)*	4.4	(.3	11)*		6.8
potato	4.3	1.2	11	52	19	120	44	3.8	250		
pumpkin	2.9	.4	11	32	9.2	87	6.7	(2	12)*		6.3
sauerkraut	1.4	.1	6.9	6.0	.9	24	.6			65	6.4
spinach	7.3	1.5	23	13	3.5	37	4.6	1.7	11		
sprouts	10.1	(4.8	20)*	25	(5	75)*					
squash	6.0	1.1	22	20			14				
sweet potato	4.0	.3	23	60	24	130	34				
tomato	1.7	.4	5.2	8.6	2.0	26	8.4	.3	66	79	7.9
turnip	7.3	2.4	18								

*"Limits" in parentheses are reported maxima and minima.

From: National Canners Association. *Liquid Wastes from Processing Fruits, Vegetables and Specialties,* D-2756. National Canners Assoc., Berkeley, CA (1974)

total discharge from facilities processing the individual commodities. Tables 1.11 and 1.12 contain information on processing wastewaters from various species of fish. Wastewater characteristics from specialty foods are listed in Table 1.13.

1.2212 Population Equivalents

Domestic sewage consumes 0.17 pound of oxygen per capita per day, on average, as measured by the standard BOD test. This figure has been used to measure the strength of organic industrial waste in terms of an equivalent number of persons. Using values from Tables 1.10 through 1.13 as examples, processing a ton of asparagus will generate, on average, the equivalent daily waste load of about 30 people; a ton of dry beans, 440 people; a ton of salmon, 38 to over 1000 people; and specialty foods, about 60 to more than 300 people. Thus, the total daily raw waste load from a single processing facility may generate a BOD load equivalent to that of a sizeable population. However, "population equivalents" are misleading and should not be used for design or surcharge purposes. The BOD of most food processing wastewaters are largely due to carbonaceous matter, whereas the BOD of domestic sewage is largely attributable to nitrogenous compounds. In a combined wastewater treatment system – i.e., a sewage treatment facility for both domestic and industrial wastes – these wastewaters tend to be complementary in terms of BOD such that treatment requirements are not represented by the sum of the two population equivalents.

1.222 WASTES FROM UNIT OPERATIONS

The volume of wastewater and the quantity of pollutants generated by unit operations vary widely between commodities and facilities. Nevertheless, certain operations at each facility contribute significantly to the discharged raw waste load. A graphical illustration of the findings at a peach cannery[1] is provided in Figure 1.05; the single largest BOD contributor was the rinsing operation following the caustic peeler.

Numerous factors influence the raw waste loads and the relative percentages from each source; some of these are discussed in detail in Section 1.3. However, industry-wide estimates have been developed during several studies.[2] Estimates of wastewater volumes from common fruit canning operations are listed in Table 1.14; the peeling operation is with mechanical peelers, compared to chemical peelers in Figure 1.05.

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1. Mercer, W. A., W. W. Rose, and E. S. Doyle. *Physical and Chemical Characterization of . . . Waste Flows Originating in a Cannery Processing Peaches and Tomatoes.* National Canner Assn. Research Foundation, Washington, D.C. March 1965.
2. National Food Processors Association. Unpublished data.

TABLE 1.11

SEAFOOD PROCESSING WASTEWATER CHARACTERISTICS

Category	Flow		BOD		SS	O&G
	(basis)	gal/ton	mg/l	lbs/ton	mg/l	mg/l
Bottom fish	105-450 gpm	–	192-1726	74	300	–
Fishmeal						
Cooling water	1440 gpm	240-480	621	–	–	–
Other wastewaters	680 gpm	510-1020	1005	–	–	–
Salmon						
Canning	0.043-0.046 mgd	–	3660-3900	6.5-178	508-4780	–
Canning	0.33 mgd	–	3860	–	2470	–
Mild curing	0.018-0.066 mgd	–	173-1320	10-80	44-456	–
Mild curing and fresh	0.011-0.036 mgd	–	206-2218	3.2-36	112-820	–
Mild curing or freezing	0.014-0.046 mgd	–	397-3082	3.8-19	40-1824	–
Sardine						
Flume water	130-300 gpm	–	200-1150	–	400	300-600
Hold water	–	–	370	–	–	–
Pump water	800-1000 gpm	–	10-45	–	–	–
Waste flume water	40-180 gpm	–	100-2200	–	100-2100	60-1340
Tuna	–	6800	895	48	1091 (58 lb/t)	287 (15 lb/t)

From: Soderquist, M. R., *et al. Current Practice in Seafoods Processing Waste Treatment,* 12060ECF04/70. U.S. Environmental Protection Agency, Washington, D.C. (April 1970)

Freezing operations generally differ from canning only in the final preservation step. Preparatory steps of washing, peeling or blanching, and sizing (slicing or dicing), and plant cleanup are essentially identical. Estimates of wastewater volumes and waste loads from fruit and vegetable freezing operations are listed in Table 1.15; these values represent discharges from larger facilities.

Generally, the largest volumes of wastewater are from raw product cleaning, including hydraulic transport, and from container cooling (in canning plants). The largest quantity of organic pollutants are primarily from rinse sprays associated with chemical fruit peelers and from vegetable blanchers. Where sizing operations (pitting, slicing, dicing, etc) are conducted, additional significant contributions to the organic load come from these units. The percent contribution to the raw waste load from major unit operations have been estimated for the major canning and freezing commodities by experienced persons in the industry (Table 1.16).[1]

1.23 Solid Residuals From Food Processing

In the production of canned, frozen and preserved foods residual materials are generated at numerous points. The term

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[1] National Canners Association. *Liquid Wastes from Canning and Freezing Fruits and Vegetables* (12060 EDK 08/71). U.S. Environmental Protection Agency, Washington, D.C. August 1971.

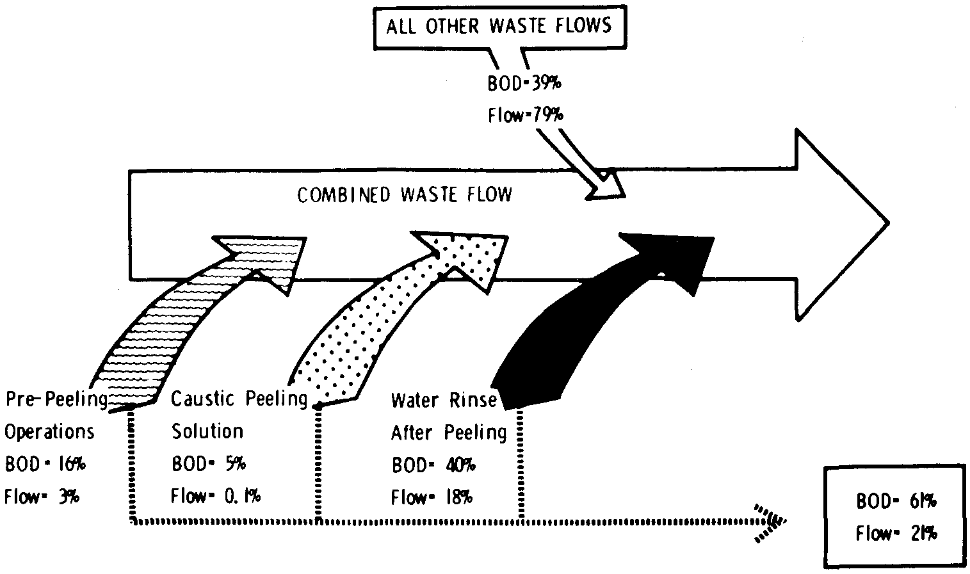

Figure 1.05. Sources and relative strengths of wastes from peach canning.

TABLE 1.12
FISH PROCESSING WASTEWATER CHARACTERISTICS*

Parameter	Unit	Value
Volume	gal/ton fish	465 - 9100
BOD_5	mg/l	2700 - 3400
	lbs/1000 gal effluent	2.6 - 29
	lbs/ton fish	8 - 120
	lbs/ton product	21 - 24
Suspended solids (SS)	mg/l	2200 - 3020
Total solids (TS)	mg/l	4198 - 21,820

*By the Washington State Water Pollution Control Commission

From: Soderquist, M.R., *et al. Current Practice in Seafoods Processing Waste Treatment,* 12060ECF04/70. U.S. Environmental Protection Agency, Water Quality Office, Washington, D.C. (April 1970)

"residuals" is used for both food and non-food materials in solid form that are not part of the plant's primary output. Some of the residuals are used in by-products and the remainder is disposed of as waste. The following discussion deals generally with the sources, quantities, and disposal methods of common materials. Details of in-plant handling procedures are in Section 2.3; utilization and disposal methods are described in Section 5.

1.231 NON-FOOD RESIDUALS

Non-food residuals include packing and other metal, wood, paper and plastic materials accumulated at food processing plants. The primary sources of such materials are the raw product receiving area, the final product packing operation, the labeling and casing area, and the warehouse or finished goods storage (Figure 1.06).

Non-food residuals are normally accumulated in suitable receptacles which are placed in appropriate areas throughout the plant where these wastes are generated. Combustible matter is periodically burned (where incineration is permitted) or disposed of at public sanitary landfill sites with non-combustibles; fiber materials are frequently baled and sold for recycling into paper and fiber products. The quantities of non-food residuals are given in the bottom of Tables 1.17 and 1.18.

1.232 RESIDUAL FOOD MATERIALS

Residuals of food materials are those substances that are delivered as raw commodities but are unusable in the primary product. This includes cull fruits and vegetables, damaged units, extraneous debris (leaves, vines, etc), as well as inedible portions of the food product (corn cobs and husks, pits, seeds, etc).

1.2321 Sources

The sources and character of food residuals are determined by the commodity being processed. Generalized sources of fruit and vegetable residuals are indicated in Figure 1.07; seafood residuals, in Figure 1.08.

Fruit and vegetable residuals may be whole units of product which are determined to be unusable and are discarded; culls (immature, under- or oversized, blemished), overripe, and damaged units are discarded during inspection/sorting and during size and quality grading. Extraneous debris, such as leaves, vines, and dirt, are removed during unloading and initial washing. Skins and seeds or pits from fruits are removed during peeling and sizing (pitting, coring, cutting, pulping); cobs and husks from corn, skins and crowns from root vegetables, and stems and inedible portions of other vegetables are removed during sizing (cutting, peeling, trimming). Product fragments are usually separated after sizing. Usable food materials are frequently wasted through inadvertent spillages which may occur at any point in processing.

Although seafood residuals may be whole units, the bulk of the solid materials are inedible portions of the raw product. Fish scales or mollusk shells may accumulate in the receiving area. Trash, fish, rejects, and loose shells are removed during the initial sorting. Trimming (cleaning, butchering, deveining,

TABLE 1.13
WASTEWATER AND GENERATED POLLUTION LOADS BY COMMODITY GROUP – SPECIALTY FOODS

Category	Volume 1000 gal/ton	BOD		SS		Total P		TKN		Oil & Grease	
		mg/l	lbs/ton	mg/l	lbs/ton	mg/l	lbs/ton	mg/l	lbs/ton	mg/l	lbs/ton
Prepared dinners	2.9	1900	34	1500	28	21	0.38	45	0.88	2000	30
Frozen bakery products	2.6	3200	46	2200	28	7	–	36	–	820	–
Dressings, sauces, spreads	0.7	2600	15	1200	7	11	0.03	14	0.04	2000	6
Meat specialties	2.4	820	19	460	12	11	0.10	48	0.57	300	4
Canned soups, baby foods	5.3	560	24	320	15	7	0.18	19	0.47	–	–
Tomato-cheese-starch combinations	6.9	370	14	220	12	6	0.28	15	0.23	–	–
Sauced vegetables	20.4	310	50	250	42	4	0.09	13	0.05	–	–
Sweet syrups, jams, jellies	0.6	2400	10	400	2	19	0.05	18	0.04	–	–
Ethnic foods	3.4	570	14	200	6	14	0.14	21	0.28	170	3
Breaded frozen products	11.5	2400	52	3700	52	22	0.35	76	2.60	–	–

All figures are averages

From: Schmidt, C. J., J. Farquhar, and E. V. Clements, III. *Wastewater Characterization for the Specialty Food Industry,* EPA-660/2-74-075. U.S. Environmental Protection Agency, ORD, NERC, Corvallis, OR (December 1974)

TABLE 1.14
WASTEWATER VOLUMES FROM FRUIT CANNING OPERATIONS

Operation	Gallons/ton	Percent of Total flow
Peeling	48	2
Spray washing	385	17
Sorting, slicing, etc	120	5
Exhausting of cans	48	2
Thermal processing	24	1
Container cooling	945	37
Plant cleanup	840	33
Box washing	70	3
TOTAL	2480	100

schucking) is performed to remove inedible materials; this is the major source of seafood residuals. Rejects, substandard product, fragments, and other undesirable materials are removed during final inspection. Spillages, primarily in the packing area, result in the loss of otherwise usable product.

Food residuals are generally accumulated at a central point on the plant premises. Transport of waste materials from various areas of the plant may be receptacles or by belts or other "dry" conveyors. Hydraulic transport systems, either flumes, pumping systems or gutters, are frequently employed and solids are separated from the wastewater with screening devices.

1.2322 Quantities

The quantities of solid residuals generated during the production of major fruits, vegetables, and seafoods in the United States were determined for the base year of 1968.[1] The total residuals from each product each month, the total residuals annually generated, and the total tonnage of raw product delivered to the industry are listed in Table 1.17. Non-food wastes are given separately; the main part of the table deals with residuals that orginate as part of the food product, including inedible parts such as cobs and shells.

The reported values in Table 1.17 reflect the highly seasonal operations for such products as corn, tomatoes, and peaches, in contrast to the nearly continuous operations for specialty products and the minor month-to-month fluctuations

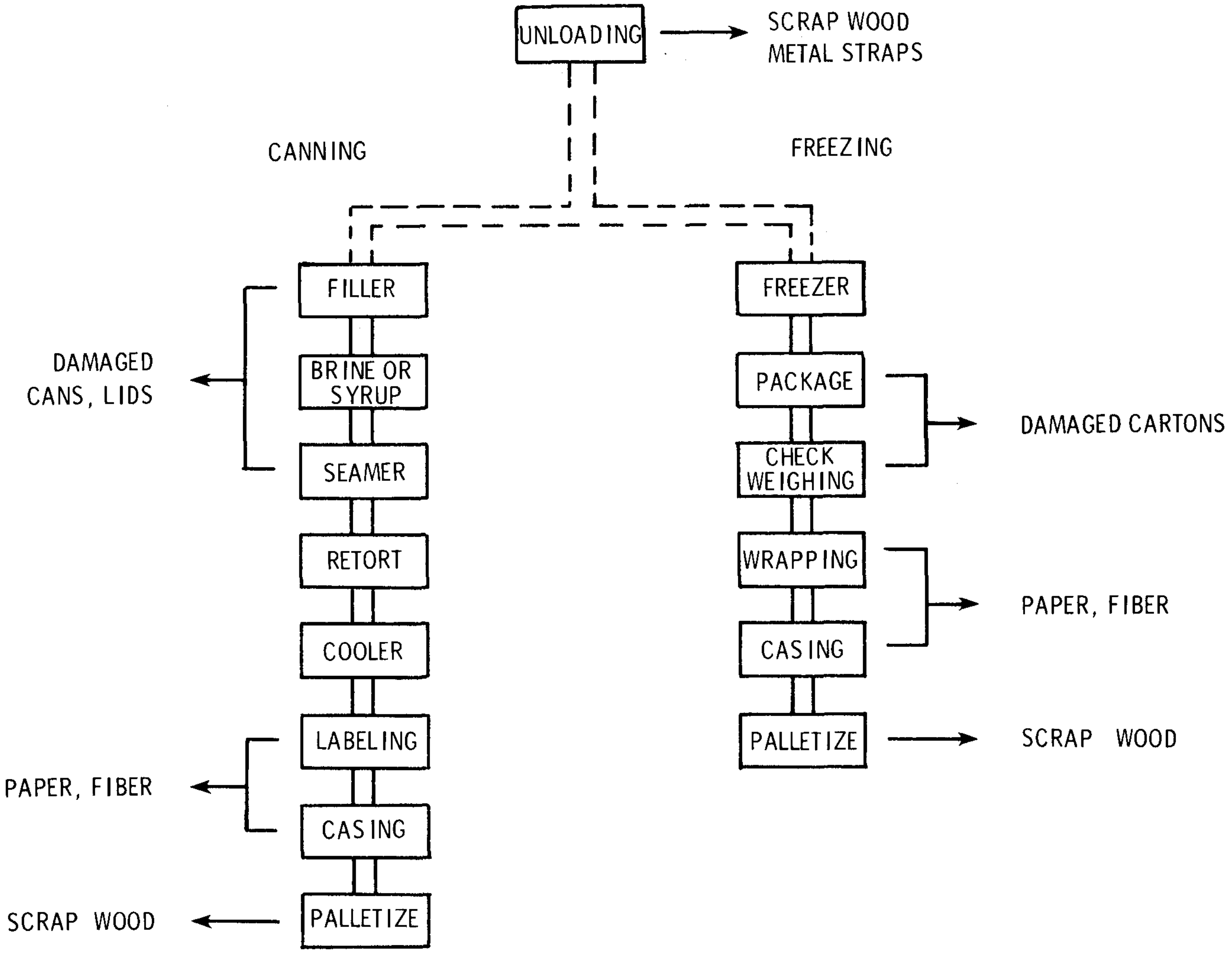

Figure 1.06. General processes and sources of non-food residuals.

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[1] Katsuyama, A.M., N.A. Olson, R. L. Quirk, and W.A. Mercer. Solid Waste Management in the Food Processing Industry (PB-219 019). National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA. 1973.

TABLE 1.15
WASTEWATERS FROM FRUIT AND VEGETABLE FREEZING OPERATIONS

Operation	Volume mgd	Waste Load, lb/day BOD	SS	TDS
Washing	0.15-0.50	500-3000	500-4000	300-1500
Belt conveyors	0.20-0.10	30- 100	100- 200	30- 100
Sorting Pitting } Sizing Slicing	0.02-0.15	50- 600	150- 700	100- 500
Blanching/peeling	0.15-1.15	1500-4000	1000-4000	2000-4000
Plant cleanup	0.60-0.20	320-1200	300-1500	320-1000
TOTAL	0.40-2.10	2400-8900	2050-104000	2660-7100
AVERAGE	1.25	6200	6200	5000

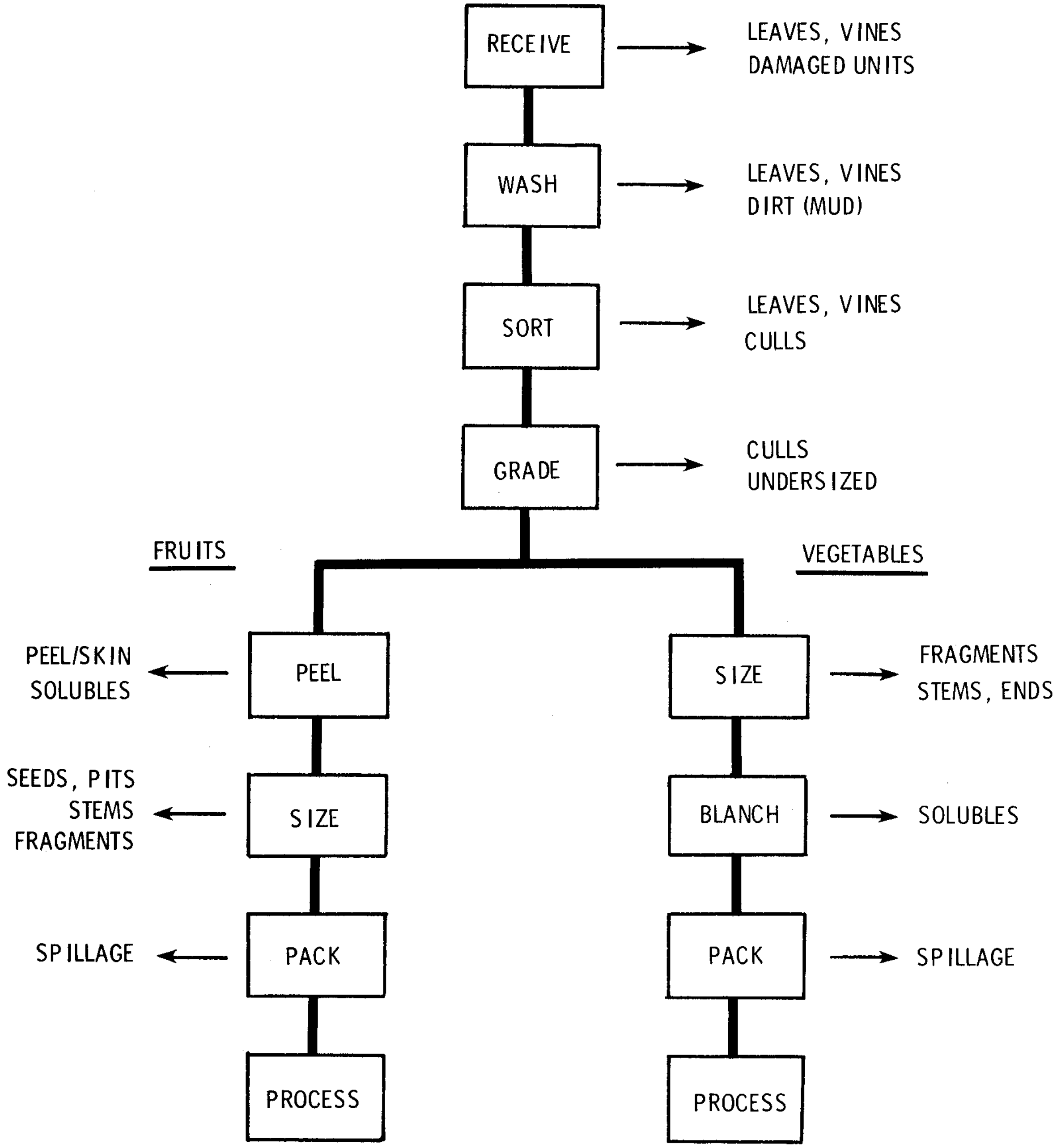

Figure 1.07. General processing operations and sources of fruit and vegetable residuals.

TABLE 1.16
WASTE GENERATION (PERCENTAGES) FROM FRUIT AND VEGETABLE UNIT PROCESSING OPERATIONS

	Clean	Peel	Cut, pit	Pulp	Fill, ht, syrup	Exhaust, seal, cook
Apple (4)**						
water	20-30***	5-20	10-25	10	40-65	
B/COD	5-20	10-40	5-40	70	10-80	
SS	2-15	15-40	3-35	85	10-80	
Apricot (3)						
water	20-95	—	5-40	—	15-15	25-40
B/COD	20-20	—	40-55	—	15-30	10-10
SS	30	—	40	—	20	10
Cherry (3)						
water	30-60	—	3-6	—	35-65	
B/COD	10	—	80	—	10	
SS	35	—	60	—	5	
Peach (3)						
water	15-20	25-50	15-35	—	10	10-20
B/COD	5-10	35-50	30-50	—	5-10	2-5
SS	5-10	30-60	25-55	—	5	2-5
Pear (3)						
water	30-60		7-30	—	10-13	30-40
B/COD	50-78		10-40	—	5-10	2-5
SS	45-83		10-45	—	5-5	2-5

	Clean	Peel	Cut	Blanch	Fill, brine, seal, cook	Fill, freeze
Asparagus (2)						
water	20-40	—	10-20	25-30	15-40	5
B/COD	20	—	10	60	10	5
SS	50	—	10	30	10	5
Beans, snap (4)						
water	30-40	—	0-40	10-45	20-50	5-10
B/COD	10-60	—	0-20	40-60	0-20	5
SS	30-80	—	0-30	20-30	0-10	5
Beet (2)						
water	10-30	30-40	20-26	—	20-24	—
B/COD	15-20	50-60	20-20	—	5-10	—
SS	15-30	50-70	10-20	—	0-5	—
Carrot (2)						
water	12-30	30-40	20-28	0-5	15-20	—
B/COD	16-20	50-60	20-21	0-10	0-3	—
SS	10-18	40-65	15-40	0-10	0-2	—
Corn, canned (2)						
water	30-40		40-41	—	20-29	—
B/COD	20-30		50-75	—	5-20	—
SS	10-15		70-80	—	5-20	—
Corn, frozen (2)						
water	19-40		26-30	25-50	—	5-5
B/COD	10-18		30-68	13-55	—	1-5
SS	10-15		70-80	5-15	—	0-5
Pea (3)						
water	50-60	—	—	10-30	20-40	5-10
B/COD	45-55	—	—	40-45	5-10	5
SS	55-65	—	—	30-35	5-10	5
Potato, sweet (1)						
water	30	35	15	—	20	—
B/COD	25	50	20	—	5	—
SS	25	40	30	—	5	—
Pumpkin, squash (1)						
water	10	20****	20	20	30	—
B/COD	15	30****	35	10	10	—
SS	10	25****	50	10	5	—
Spinach, greens (4)						
water	20-60	—	0-10	10-40	15-55	5-10
B/COD	15-30	—	10-30	30-60	10-20	5
SS	30-60	—	10-40	20-20	10-10	5
Tomato, whole (2)						
water	50-80	10-40	—	—	10-10	—
B/COD	60	35	—	—	5	—
SS	70	30	—	—	0	—

TABLE 1.16 (continued)

	Clean	Peel	Cut	Blanch	Fill, brine, seal, cook	Fill, freeze
Tomato, pulped (3)						
water	30-85	5-30****	–	–	10-60	–
B/COD	95	5****	–	–	0	–
SS	95	5****	–	–	5	–

*"Clean" includes washing, sorting, shaking, blowing, etc.; "peel" and "blanch" include related steps such as rinsing; "cut" includes slicing and dicing.

**Number of estimates in ().

***Where two or more estimates were available, the highest and lowest are shown.

****Pulping operation (not peeling).

From: National Canners Association. *Liquid Wastes from Canning and Freezing Fruits and Vegetables* (12060 EDK 08/71). U.S. Environmental Protection Agency, Washington, D.C. August 1971.

TABLE 1.17
INDUSTRY SOLID RESIDUALS BY PRODUCT AND MONTH

Product	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	Raw Tons
asparagus			4	14	14	9	2	x					42	120
lima bean						x	x	5	8	5	x	x	19	120
snap bean				2	2	7	37	41	35	9	1		130	630
beet	2			2	1	1	9	16	18	22	14	3	90	270
broc., sprouts, cauliflower	7	6	7	7	6	7	5	13	13	16	16	10	110	260
cabbage	4	4	4	3	2	1		8	14	16	14	7	76	230
carrot	6	3	4	5	4	5	9	10	23	33	26	12	140	280
corn						8	70	620	590	280	48		1620	2480
greens, spinach	2	2	8	7	3	1		x	2	2	3	2	33	240
mushroom	3	3	3	3	3	3	2	2	2	3	3	3	32	67
pea				1	5	25	28	11	1	x	x	x	74	580
wh. potato	99	90	92	86	90	62	69	100	110	130	130	120	1170	3570
pump./squash							1	12	10	22	10		55	220
tomato	7	7	6	6	10	70	140	150	110	6	6		520	6970
vegetable, misc	11	12	12	11	17	19	30	38	36	38	32	16	270	1220
apple	28	21	15	5	4			2	33	53	64	56	290	1050
apricot	x	x	x	x		6	7						16	120
berry	x	x	x	x	x	3	3	4	2	x			14	200
cherry					x	1	13	11					26	190
citrus	330	330	330	330	330	330	210	100	100	160	210	330	3080	7800
fruit, misc	x	x	x	x	1	3	4	8	9	8	2	1	36	150
olive	1	1	x		x	x	x		2	3	3	x	11	85
peach						23	84	99	83	3			290	1100
pear							14	33	39	25	6		120	410
pineapple	25	25	30	50	55	55	55	55	30	25			400	900
plum, prune	1	1	1	x		1	x	x	1	1	x	x	7	27
dry bean	1	1	1	1	x	x	x	x	x	1	1	1	7	230
pickle	x	x	x	x	x	8	9	8	8	6	x	x	41	560
specialty	26	26	26	26	25	24	23	24	24	25	25	26	300	2500
clam, scallop	1	1	1	1	1	1	1	1	1	1	1	1	13	90
oyster	3	3	2	2	x					2	2	3	18	20
crab	2	2	2	2	1	2	1	2	2	2	2	2	22	30
shrimp	5	7	7	6	8	5	5	5	5	5	5	5	66	120
salmon	x	x	x	x	x	8	12	10	8	2	x		40	124
sardine	x	x	1	1	x	1	1	1	1	x	x	x	6	26
tuna, misc. seafood	7	7	7	7	8	8	9	10	10	9	9	7	99	520
TOTAL	570	550	560	580	590	700	860	1400	1330	920	640	600	9310	33500
Non-Food	39	38	40	43	43	55	69	76	78	73	49	43	650	

All figures x 1000 tons; rounded (after adding)
x = 500 tons or less

TABLE 1.18
INDUSTRY SOLID RESIDUALS BY PRODUCT AND DISPOSAL METHOD

Product	Total Raw Tons	fill	spread	burn	Total as Solid	water	pond	sewer	irrig	Total in Liquid	feed	other	Total by-product	Total resid-uals	Not acc't. for
asparagus	120	8	16		24					0	19		19	42	3
lima bean	120	1	8		10					0	10		10	19	(–3)
snap bean	630	35	32		67		x	3		3	64		64	130	0
beet	270	18	46		65			6		6	18		18	90	21
broc., sprouts, cauliflower	260	12	9		21			1		1	91		91	110	x
cabbage	230	19	44		64		6			6	6		6	76	(–1)
carrot	280	6	30	x	36			2		2	100	x	100	140	10
corn	2,480	3	86	x	89			2	1	3	1,530		1,530	1,620	42
greens, spinach	240	5	3		8		x	x		x	24		24	33	4
mushroom	67	4	28		32	x				x			0	32	(–2)
pea	580	3	22	x	24					0	49	x	49	74	4
wh. potato	3,570	57	28		85	42	2	4		48	1,040		1,040	1,170	170
pump./squash	220	8	13		22		x	9		9	24	2	25	55	97
tomato	6,970	250	130	x	380	21	7	x	1	30	120		120	520	150
vegetable, misc.	1,220	38	71	4	110		1	52		52	110		110	270	x
apple	1,050	35	54		90	x	x		x	x	110	87	200	290	30
apricot	120	4	2		6	x				x	7	2	9	16	5
berry	200	4	5	1	10	2	x	x		2	1		1	14	2
cherry	190	15	5	x	20				1	1	4	x	4	26	1
citrus	7,800	4	76		80				1	1	3,000	3	3,000	3,080	310
fruit, misc.	150	13	13		25			x		x	8	2	10	36	3
olive	85		1	x	2		x			x		10	10	11	x
peach	1,100	130	56		180	13	x	1	x	14	50	44	94	290	(–19)
pear	410	40	32		72	10		x		10	36		36	120	14
Pineapple	900	30			30	5		5		10	360		360	400	0
plum, prune	27	4	2		6	1				1	x		0	7	1
dry bean	230	3	2	x	6			x		x	2		2	7	(–1)
pickle	560	37	3		40			1		1			0	41	(–15)
specialty	2,500	37	3	8	48		7	18	x	24	210	17	230	300	0
clam, scallop	90	8	4		12	x				x			0	13	65
oyster	20				0	2				2		16	16	18	x
crab	30	5	1		6	16				16			0	22	1
shrimp	120		4	3	7	29		12		41	16	x	17	66	20
salmon	120				0	35				35	4	2	6	40	3
sardine	26				0					0		6	6	6	x
tuna, misc, seafood	520				0	x				x	69	30	99	99	91
TOTAL	33,500	830	830	18	1,680	180	24	120	5	320	7,080	220	7,300	9,310	1,010
											metal	other			
non-food		300	17	97	410	x	32			32	130	67	200	650	–

All figures x 1000 tons; rounded (after adding)
x = 500 tons or less

in processing potatoes, citrus, some seafoods, and other products. Seasonal operations were found to be even more marked within regions as compared to the United States as a whole. Just a few products accounted for the bulk of the raw tonnage and of the residuals generated by the industry; for example, about 70 percent of each were from citrus, tomatoes, white potatoes, corn, and specialties combined; more than half were from the first three of these products. Non-food residuals were only a small fraction of the total.

Numerous factors influence the quantity of residuals generated for each commodity. Foremost among these are seasonal climatic conditions which affect the quality of the raw product, the extent of insect infestation and damage, harvesting techniques which determine the extent of product damage and maturity, the raw product quality standards as determined by the finished product (e.g., whole vs. puree), the number of styles packed (e.g., whole only vs. whole, sliced, diced, and puree), and the seasonal variations in raw product availability. All of these factors influence "case yields," a term commonly used by the industry. The quantity of residuals will nearly equal the calculated losses for most products.

1.2323 Disposal Methods

Information on the disposal methods for food processing residuals was elicited during the previously cited study; the quantities by product and disposal method are listed in Table 1.18. Detailed discussion, of suitable methods are in Section 5.

Three columns in the table break down the tonnages handled as solid (sometimes as wet solid) wastes and are summed in the column "Total as Solids." "Fill" does not imply frequent covering and compacting as required for sanitary landfilling; the actual practices varied from these to simple dumping. "Spread" disposal is usually on agricultural land and may or may not include discing. "Burn" refers to mostly non-food materials burned at the site of the food processing plant.

Tonnages of solid residuals disposed of in liquid medium are listed in four columns and as a total. "Water" means a stream, lake, bay or ocean; "pond," a holding or treatment

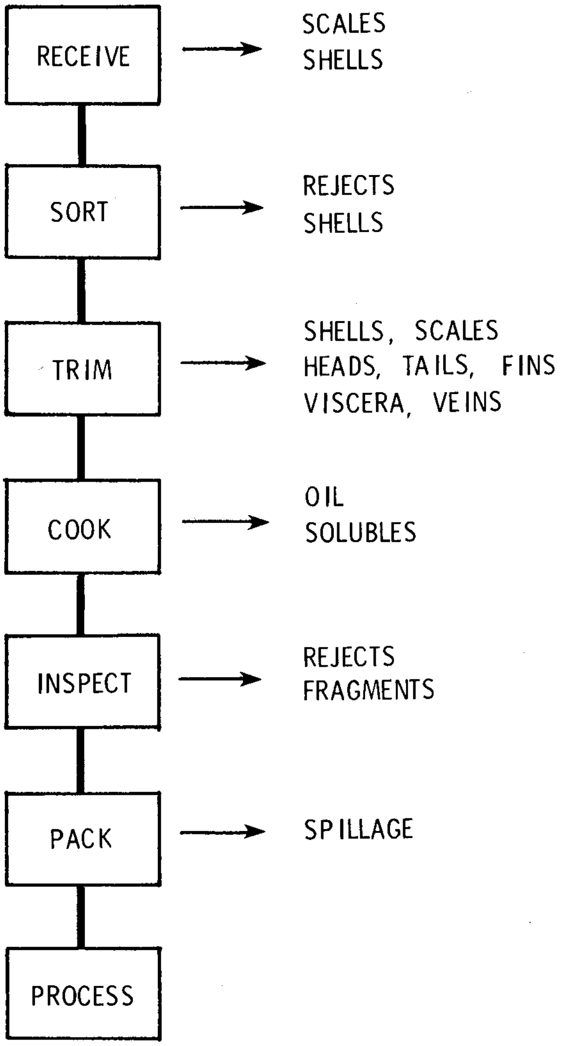

Figure 1.08. General processing operations and sources of seafood residuals.

pond; "sewer," a public treatment system; and "irrig," disposal by irrigation. Small percentages of all products are leached or comminuted and disposed of in the plant liquid waste stream aside from the tonnages listed; these quantities constitute the organic load of wastewater discharges and were not included in the study.

By far the largest proportion of by-products from food processing residuals went into animal feed. The column headed "other use" includes smaller amounts for charcoal, alcohol, oil, vinegar, and some other products. Non-food by-products have separate headings, "metal" and "other"; the latter is mostly recovery of paper and cardboard.

The data illustrate wide variations in disposal practices from product to product. More than three-fourths of the total food residuals were used in by-products. About 5.6 of the total 7.1 million tons of residuals used as animal feed were from only three products: citrus, corn, and white potatoes. These are all large crops, producing large percentages of residuals, and generally processed in regions where there are livestock to consume the residuals. Citrus and potatoes are processed the year around and corn residuals are made into silage which can be stored; the feed by-products are, therefore, available over long periods. Some of the tonnages reported as fed to animals were spread on the land for livestock to eat, but undoubtedly portions were trampled and wasted. On the other hand, some of the tonnages reported (and summarized) as waste spread on land were probably handled in the same way. Only 3 percent of the food by-products were for uses other than animal feed. These included oil from olives, charcoal and other by-products from peach and apricot pits, vinegar from apples, alcohol from various fruits, oil and fertilizer from some seafoods, and oil and other by-products from citrus.

Fill and spread methods were about equally utilized for solid waste disposal, but the proportions to each of these methods varied widely among products. Only small quantities of residuals were burned at the plant site; very few of the industry's food waste products would burn without prior dehydration (cull dry beans, onion skins, and a few others), but much of the non-food waste is combustible.

Disposal of residuals to "water" (stream, lake, bay, ocean) was in large measure by seafood plants returning fish and shellfish remains to the medium from which they came. Small percentages of the residuals from the fruits and vegetables were discharged to water or were treated in company ponds and irrigation systems or municipal plants. These quantities are expected to diminish due to increasingly stringent discharge requirements and costs associated with treatment.

1.3

FACTORS INFLUENCING THE GENERATION OF WASTES

The variability of food processing waste characteristics has been mentioned repeatedly throughout the preceding discussions and has been substantiated by every study of food processing facilities. Numerous factors affect the generation of wastes from processing foods, including unique physical features which lend individuality to each plant. Therefore, the importance of developing raw waste load data for each plant cannot be overemphasized. The data cited or alluded to in this section are from a recent study.[1]

Some of the factors are discussed in this section under several headings. Details describing measures for reducing the impact of some of these are in Section 2; however, many of these factors are obviously beyond the control of the processor. The extent to which these latter factors influence waste generation cannot be quantified since their relationships to the generated waste loads are complex and overlapping. Nevertheless, the reality of their influence should not be ignored, especially for the establishment of discharge requirements and the development of design criteria.

1.31 Commodity

On average, wide ranges of wastewater volumes and of generated pounds of pollutants per ton are found between different commodities. Examples for wastewater are plotted in Figure 1.09 and for BOD in Figure 1.10 (also see Table 1.10). Although the average differences between commodities are large and significant, the variability among plants processing the same commodity is much greater. This is shown by the probability limits of the data – the upper and lower values expected to encompass 95 percent of the plants processing each commodity. In spite of the large differences in averages, the distributions of all of the commodities overlap one another. In most instances generation of wastes varies more than twenty-fold within commodities and is sometimes even more variable. Some of the reasons for the wide variability within commodities are discussed below.

1.32 Product Style

The kind of product made from a given commodity greatly influences the volume of wastewater and the quantity of pollu-

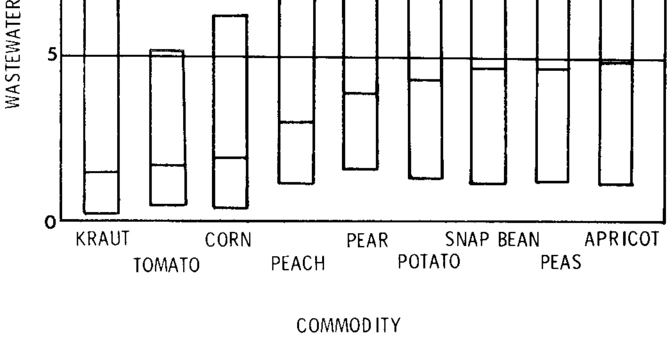

Figure 1.09. Generated wastewater: average and range (95% limits).

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1. National Canners Association. Liquid Wastes from Processing Fruits, Vegetables and Specialties (D-2756). National Canners Association, Berkeley, CA. 1974.

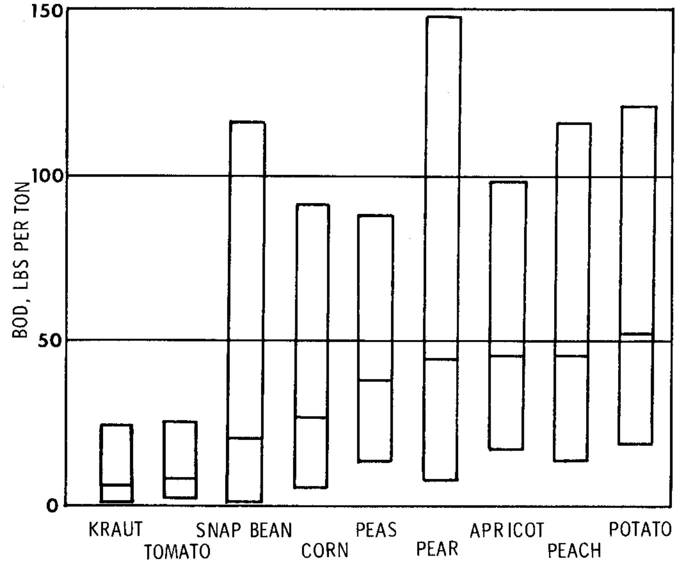

Figure 1.10. Generated BOD: average and range (95% limits).

tants. This influence is illustrated in Figure 1.11 where the generation of BOD is compared to the percentage of tomatoes that are peeled – the more peeling, the more BOD on average.[1] The relationship is highly significant in spite of the wide probability limits. In a recent study[2], slicing apples, slicing snap beans, peeling tomatoes, and cutting beets and carrots generated significantly greater amounts of BOD, compared to other styles. In data from eight commodities, 21 percent of the variability among plants in the generation of BOD was accounted for by style. Information elicited during this study on the volumes of water used in the processing of various product styles is summarized in Table 1.09.

As more styles of a given commodity are processed at a facility, the extra operations associated with each style add to the water requirements. For example, each added style may require an additional washing, as well as additional equipment that must be cleaned, thereby increasing water consumption and adding to the hydraulic load. Each opportunity for water to contact food products results in the generation of additional organic loads from leached soluble solids and physically removed suspended matter. This becomes increasingly significant as the product particles are reduced in size (halves, slices, dices) due largely to the rupturing of plant (botanical) cells and the exposure of larger product surface areas.

In general the cooking and cooling of canned products require more water than condensor water requirements for frozen products. However, many vegetable commodities must be blanched prior to freezing but not canning, thereby requiring more water and generating additional pollutants.

1.33 Raw Product Quality

The condition of the raw product as received for processing has an important bearing on the generation of wastes. However, there are no standard measures of raw product quality for many commodities and quantifications of the effect are sparse. Nevertheless, there is no question that overly mature and damaged fruits and vegetables, as well as those that have been trimmed to remove natural defects, contribute much more to the organic load by abrasive losses and leaching. Mechanically harvested products which are heavily laden with soil require more extensive cleaning than less contaminated products, resulting in larger volumes of wastewater containing high concentrations of suspended solids. The maturity, extent of product damage, and the number of defects depend on weather, other growing conditions, delays between harvest and delivery, and other factors that have not been extensively studied. These factors will vary among regions, years, and days within the same year.

A measure of the influence of raw product quality on waste generation may be deduced from extensive records of BOD generation at a tomato plant where average quantities were 6.0, 5.5, and 11.9 pounds of BOD per ton of tomatoes in three consecutive years. The generation doubled in the absence of operational changes that could account for differences. Similarly, in two-year records the BOD generated per ton varied two-fold between years at an apricot and at a pea plant. The suspended solids per ton varied more than four-fold at the apricot plant, and three-fold at both a lima and a pea plant. In all cases there were no in-plant changes to which these differences could be attributed.[1]

1.34 Harvest and Transport

The method and conditions of harvesting have significant impacts on waste generation. Hand picking of fruits and vegetables generally results in more uniform maturity and, hence, minimal losses from sorting at the processing plant; also, extraneous debris, such as leaves, vines, and soil, are minimized in the delivered crops. However, mechanical harvesting techniques are being employed for an increasing number of commodities. Although extensive horticultural efforts are being directed toward the development of uniform ripening and damage resistant strains, mechanical harvesting generally results in increased waste loads per ton at the plant, especially during damp weather. Not only are the extent of damage and the presence of culls and debris increased, but also the quantity of soil which must be washed off with larger volumes of water. For example, mechanical harvesting of tomatoes may increase field soil, often present as tightly-adhering smears and large clods, from a trace to as much as two percent of the weight of product.

Transportation methods also influence the generation of waste since they affect the condition of the raw product. Generally, the smaller shipping containers, such as lug boxes and baskets, result in less damage to the commodity than large containers, such as bins and bulk trailers. The distance between the harvest area and the plant, as well as the time between harvest and processing, have also been demonstrated to affect a number of commodities. Attempts to control the impact of these factors are normally made to maximize final product yields. Such controls will simultaneously reduce waste generation.

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1. National Food Processors Association. Unpublished data.
2. National Canners Association. Liquid Wastes from Processing Fruits, Vegetables and Specialties (D-2756). National Canners Association, Berkeley, CA. 1974.

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1. National Food Processors Association. Unpublished data.

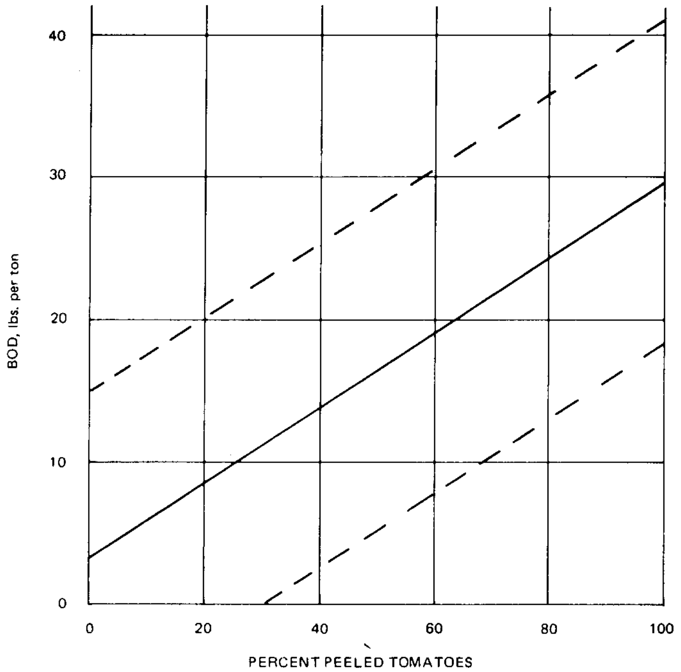

Figure 1.11. BOD generation as a function of tomato peeling (with 95% limits).

1.35 Plant Size and Age.

The forementioned study revealed that among plants processing the same commodity, larger plants tended to discharge less wastewater per ton. Although the reasons for the negative relationship between wastewater volumes and plant sizes were not delineated, the correlation was statistically significant. A major factor may be that the efficiency of water use is inherently higher in larger facilities, even when similar equipment is utilized; for example, the data indicated that the proportion of reused water increased with increasing plant size. Also, larger facilities often consist of multiple and identical processing lines, enabling them to more consistently maintain an even flow of product over each (see Processing Rate discussion below).

The generation of organic loads (BOD/SS per ton) did not correlate well with plant size. Although a negative correlation was indicated, the data were not statistically significant.

Plant age has little or no apparent bearing on generated wastes. The age of the structure does not correlate to the age of the equipment currently in use. Equipment replacement and upgrading occurs randomly throughout the industry such that many plants include a mixture of old and new equipment. However, older equipment is expected to be less efficient and therefore to generate more waste than new equipment.

1.36 Processing Rate and Percent of Plant Capacity

Processing plants typically experience wide ranges in tons of raw product processed per day, due primarily to the variability in product availability. Each facility is designed to handle a fixed maximum quantity of raw product per hour. In practice food processors commonly use about 80 percent of the plant's design capacity and sometimes much less. The "excess" is needed to handle glut conditions created by excessive product availability which frequently occurs within a season and by bumper crops which could occur any year. Both wastewater volumes per ton and BOD generation per ton are negatively related to the tons of product and, hence, to the percent of used plant capacity.

The water supply to some equipment cannot be effectively regulated, that is, a fixed amount is required whenever that unit is in operation. Thus, water use efficiencies increase with processing rates, reaching the maximum when the plant capacity is fully utilized, thereby explaining the negative relationship between wastewater volume and processing rate. However, the relationship between BOD generation and processing is not as clear. The most likely reason is that larger tonnages force shifts in the proportion of product styles to maximize raw product utilization and even out product flows, thereby reducing waste generation.

1.37 Preparation Procedures and Equipment

Differences in preparation equipment are associated with the style of the product. For example, pitters may or may not be used in processing such fruits as cherries, plums, and olives; a variety of cutters and slicers are used in some plants for peaches, pears, apples, snap beans, spinach, root crops, and other commodities; size graders are needed for efficient preparation of some commodities; specific gravity graders may be used on peas and limas; and mechanical corers are needed for some styles of apples. All of these alternative preparation steps use water and generate pollutants to varying degrees.

The design and mode of operation of each piece of equipment influence the generation of waste within product style. Most equipment now in use was designed with primary considerations of high production rates, retention of product quality, and ease of sanitation. Very little attention had heretofore been devoted to the influence of equipment design and operation on wastes. For example, in a recent industry study about 12 percent of the BOD generation and 9 percent of the suspended solids generation at apple, beet, carrot, pear, and tomato plants were associated with a measure of the type of peeling equipment in use; also, significant differences in waste loads were found between types of shrimp peelers. However, recent modifications to existing technology and new developments have contributed markedly toward reducing waste loads from major contributing sources. Most of the steps in preparing foods for canning, freezing, and dehydrating can now be done in more than one way and the difference in the generation of wastes is one of several factors that should be considered in choosing a preparation method. Peeling and blanching are such steps; other examples are mentioned below and in Section 2.

For those commodities which are peeled, from 30 to 60 percent of the total plant pollutional load is commonly contributed by peeling; for blanched commodities, from 10 to 60 percent of the load commonly comes from blanching. Low waste equipment has been developed for both procedures. Dry caustic peeling is reported to reduce the waste water flow from the peeling operation by 80 to 90 percent and the pollutant load for peeling by 60 to 90 percent in processing potatoes, beets, and peaches. The dry caustic equipment is more expensive, however, than conventional peelers. Modified blanching methods have reduced the blanch wastewater by two-thirds and more and the generation of pollutants in the blanching operation by about the same degree for peas, limas, corn, snap beans, and spinach. Again, however, higher costs, as well as decreased yields for some commodities, can be problems.

1.38 Water Use

As previously discussed, water is both recycled in the same piece of equipment (for example, returned from the end to the beginning of a flume) and reused from one operation to another, typically from a later to an earlier step in preparation. The percentage of reused water varies among plants from little or none to more than 90 percent and tends to increase on average with increasing plant size. Cooling, chlorinating, or other renovation may occur between uses (see Section 2). About 40 percent of the plants separate their relatively clean wastewater (typically cooling or condensing water) from that with a higher pollutant load and dispose of the two streams separately; the clean water is frequently a source of water for reuse.

Water is commonly used to transport the product between preparation steps with advantages economically and in maintaining sanitation. The amount of water transportation varies widely among plants and somewhat on average among commodities. The contribution of water transportation to the pollutant load depends on the stage in preparation at which it occurs (see below). Among commodities with a fairly high degree of exposure to leaching from this source are asparagus, snap beans, broccoli, cauliflower, carrots, mushrooms, okra, pears, potatoes, and soft squash; among those with a low degree of exposure are berries, grapes, pickles, pineapple, plums, pumpkin, and cabbage (sauerkraut). The quantity of organics leached from the product is a function of the duration of immersion and the size of the food particle (see Section 2.1); the pollutional strength increases sharply with both immersion time and decreasing size of cut.

Solid residuals from food processing (culls, peels, pits, trimmings, etc.) may be removed from the plant in a water system or by a dry transportation method. The degree of water conveyance of residuals varies widely among plants processing the same commodity but fairly consistently among commodities on average. The most has been reported in apricot, asparagus, dry bean, berry, peppers, pickle, potato, pumpkin, soft squash and turnip plants; the least in apple, cauliflower, citrus, corn, mushroom, okra, pineapple and sauerkraut plants.

Water recycling and reuse will obviously reduce the quantity of water required for processing. However, recycle and reuse generally have little effect in minimizing the organic load discharged from the facility. In contrast, water used for product and solid residual transport, compared to the use of dry transport systems, significantly increases both the volume and the organic load of wastewaters. Water conservation in product conveying is discussed in Section 2.113; alternatives for residuals transport, in Section 2.3.

1.39 Housekeeping

Although difficult or impossible to quantify, many operations in food processing which are incidental to the principal steps in preparing the product affect the quantity and the strength of wastewater. Some of these practices are briefly described here and discussed in detail in the following section.

Water running in unused equipment is a source of waste that is readily controlled. Examples are cleanup hoses which are left on between periods of use, and flumes, washers, and graders which are empty of product. All contribute unnecessarily to the hydraulic load.

Sweeping (instead of hosing) and dry conveying solid residuals save water and reduce pollutant generation. High pressure-low volume systems permit plant cleaning with efficient use of water. The continuous or intermittent but frequent application of chlorinated water to belts and other food contact surfaces makes subsequent cleanup easier and more efficient. Clean-in-place systems can be designed to clean pipes, tanks, and other equipment automatically and without wasting water. Prompt removal of residues and preventing a buildup of food deposits where water is running avoid excessive leaching. Spilled products, especially juiced commodities and syrup, are a strong source of BOD and suspended solids. If spills are unavoidable, the product should at least be kept out of the wastewater stream.

These and other practices can be controlled through a program of careful attention to reducing their impacts. Although each by itself may constitute a minor source of waste, the cumulative effect may comprise a high percentage of the total raw waste load. However, food processing demands a high level of sanitation. Whatever is done to conserve water and abate pollution must in no way compromise the sanitary conditions in a food plant and its equipment.

SECTION 2

WASTE PREVENTION AND REDUCTION

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SECTION 2

WASTE PREVENTION AND REDUCTION

LIST OF FIGURES

LIST OF TABLES

2.0

INTRODUCTION

Population growth, coupled with increasing urbanization and industrialization, has created environmental problems which urgently require solution. Foremost among the environmental issues is water pollution abatement. Although technology now exists to treat liquid wastes to any desired level, the cost of treatment increases sharply as higher effluent qualities are required. Thus, the need for reducing the volumes of liquid and solid wastes which are generated during the production of processed foods is more critical today than ever before. Water must be conserved, not only because it is a vital natural resource, but also to minimize costs incurred in the treatment and disposal of liquid wastes.

During the production of processed foods, discharge of inedible portions of raw commodities is unavoidable. Unnecessary discharge of raw product, however, is costly because of the added problems and expense of disposal, as well as higher product loss. Common disposal methods for solid wastes, such as landfill and land spreading, are in many situations becoming increasingly less practicable as a result of urban expansion.

Implementing effective and economic solutions to these waste problems is quite probably the most significant task facing the canning industry today. Public concern regarding pollution abatement is a major issue nationwide. The theme prevalent in all legislative and regulatory action is that the land, air, and waters of this country are no longer to be used for assimilation of wastes and that the responsibility for curtailing such activities lies solely with the generator of the wastes.

The canning industry has accepted the responsibility for waste management as an integral part of its activities. A positive and comprehensive program for pollution abatement has been pursued by the industry's Research Laboratories. Outstanding achievements under this program include reduction of fresh water requirements, segregation of strong wastes for separate treatment, modification of processes to minimize waste generation, education of plant personnel about pollution control, and cooperation with government agencies to develop treatment procedures.

This section of the Guide includes discussions of some of the above achievements. The reader is directed to the cited references for details and additional information. (The numbers in parentheses throughout this section refer to citations in the supplemental volume, Guide to Literature).[1] Where technical answers are not yet available, research is indicated. Research must include large-scale, demonstration-type projects whereby the economics, as well as technical feasibility, of various waste management methods can be evaluated.

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[1] Warrick, Louis F. *Guide to Literature On Waste Management For The Food Processing Industries, 1900-1975.* The Food Processors Institute, Washington, D.C. 1979.

2.1

WATER CONSERVATION

Problems and costs associated with wastewater treatment and disposal are determined by several factors, foremost among which is the volume, or hydraulic load, of wastewater requiring treatment. Food processing operations inherently require the use of water which, unfortunately, becomes wastewater that must be treated and disposed of. By minimizing the quantity of water used during the preparation of foods, the quantity of wastewater generated from food processing operations can be minimized.

The second important factor which influences the cost of wastewater treatment is the strength, or organic load, of the wastewater as determined by the amount of organic pollutants contained therein. Most of the water used in food processing operations comes into direct contact with raw product. Soluble and suspended solids are readily extracted from the raw product by water, thereby creating the high organic loads associated with food processing wastewaters. Significant waste load reductions are achievable by eliminating the use of water wherever practicable.

Cost reductions associated with reduction of water usage are not limited to waste treatment and disposal. Costs are incurred to procure fresh water, whether privately obtained or purchased from a utility, and are proportional to consumptive use. Thus, water conservation practices can offer dual economic advantages while minimizing wastewater treatment and disposal problems.

2.11 Efficient Use of Water

Water is used in food processing plants to accomplish specific tasks. These tasks may be grouped into three categories: (1) food processing, (2) general cleaning, and (3) personal use. Uses under food processing include

raw product washing
peeling and rinsing
blanching and cooling
vacuum condensing
product conveying
syrup and brine preparation
can cooling
product freezing
heat processing (including preheating, cooking, pasteurizing)

Miscellaneous applications, such as container washing and equipment lubrication, may also be included in this category. General cleaning includes plant cleanup and waste conveying; personal use includes water required for employees' personal and sanitary use and may include plant cafeteria wastewaters when applicable.

Water conservation practices can generally be observed for uses under each category. Since water used for personal purposes are generally handled separately from processing wastewaters, the following discussions will be limited to the in-plant uses graphically summarized in Figure 2.01.

Maximum efficiency of water use has been the aim of considerable research. The most desirable procedures vary from product to product and situation to situation. Significant reductions in the quantity of water used to perform specific tasks can frequently be realized by simple measures. Some of these are outlined in the following discussions of unit operations.

An in-plant survey (Section 3) will provide factual data identifying potential water economies for individual product lines. It is mandatory that such data be accumulated so that water conservation and waste reduction programs can be purposefully implemented.

2.111 AVOIDING WASTAGE

The problem of wasted water is experienced by almost all food processing plants. Unnecessary use of water must be eliminated for effective water conservation programs. Examples of frequently observed points where water is wasted are: (a) unattended hoses, (b) idle equipment, and (c) excessive

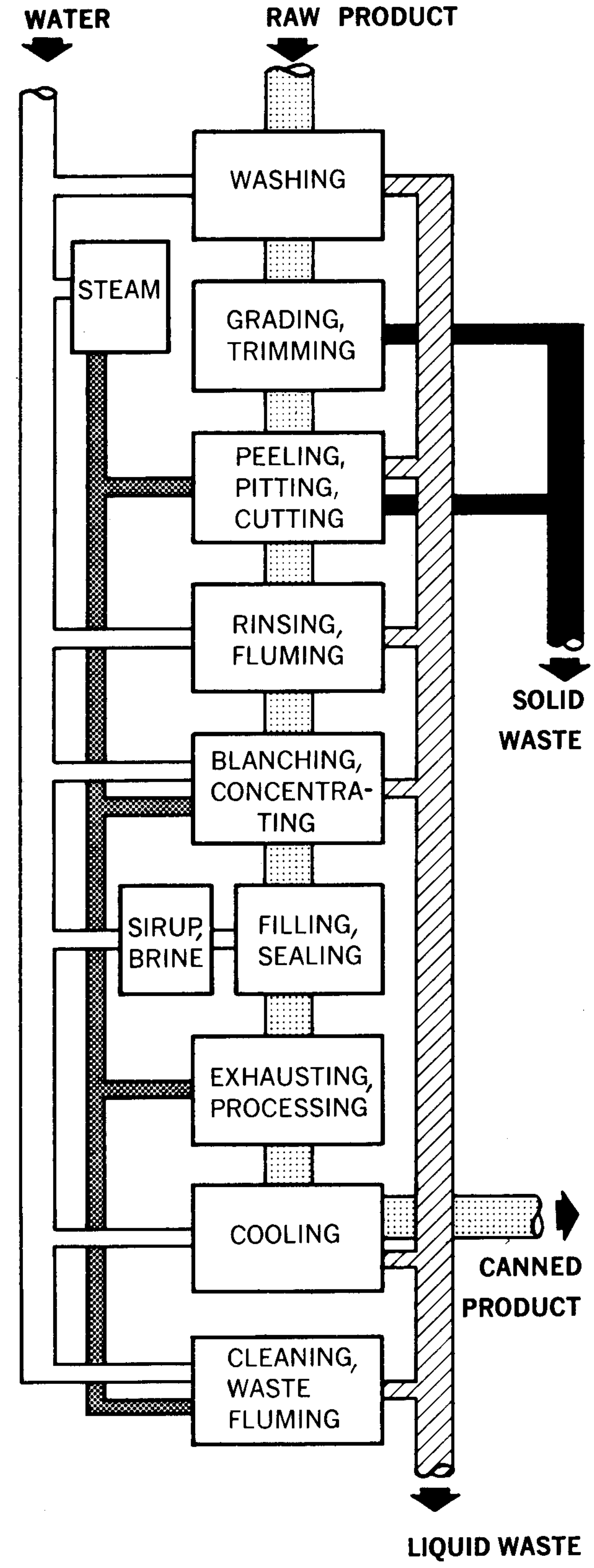

Figure 2.01. Uses of water and steam in canning.

overflows from water recirculation systems.

Hoses which are normally provided for equipment and general plant cleanup are frequently left unattended with water flowing freely onto the floor. The use of springloaded hose nozzles, which automatically shut the flow of water when released, have been successfully used in many plants to eliminate this problem.

Hoses are also often used to apply water for lubricating belt conveyors. The quantity of water consumed for this purpose far exceeds that which is required. Mist or other low volume spray heads will provide sufficient water for belt lubrication. The quantity of water saved will readily justify the cost and trouble of installing these sprays.

In multi-line plants it is not uncommon to have one or more lines idle during various times of each production day. When a line is shut down, even for short durations, water being supplied to various operations in that line should be turned off. Lubricating sprays in idle equipment and water flowing in unused flumes and washers contribute unnecessarily to the volume of the plant effluent.

Dump tanks, washers and other recirculated water systems are operated with continuous fresh water additions, resulting in continuous overflows of wastewater. Fresh water is generally provided to maintain sanitary and aesthetically acceptable conditions within the systems. However, flow rates should be adjusted to the minimum level required to accomplish this task. Indiscriminate adjustment of flows results in excessive wastewater volumes. (Methods to minimize water consumption by these systems are discussed in Section 2.12, In-plant Reuse of Water, and Section 2.23, pH Control of Recirculated Water.)

Effecting the elimination of wasted water requires the cooperation of all plant employees. Education programs, emphasizing the role each employee can take in the overall environmental effort of the company, have yielded encouraging results for many plants. In one such case water consumption was reduced from 2,300 gpm to 1,550 gpm, a 32.6% savings. Using the current fee schedules of five different cities, this would represent a sewer surcharge savings based on volume of from $26 to $134 per day. Additional savings in the cost for fresh water would result in at least a two-fold total savings. The dual cost savings associated with reductions in the consumptive use of water is graphically illustrated in Figure 2.02.

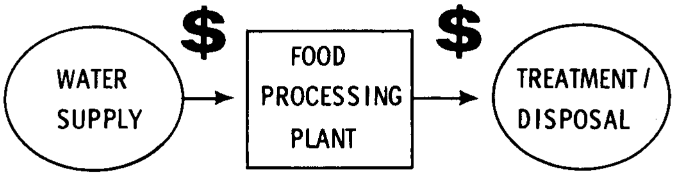

Figure 2.02. Expenses are incurred for the procurement *and* disposition of water.

2.112 PRODUCT WASHING AND RINSING

One of the principal uses of water in processing fruits and vegetables for canning or freezing is for cleaning raw commodities. Several washing and rinsing operations are generally provided to remove such materials as:

1. Microorganisms, especially mold and spoilage bacteria.
2. Soil.
3. Insect eggs and fragments.
4. Chemical residues, such as insecticidal dusts and sprays.
5. Organic debris, such as leaves, stems, or product fragments.

TABLE 2.01
EFFECTIVENESS OF WASHING IN REDUCTION OF CONTAMINATION BY EXTRANEOUS MATTER[1]

Product	Function	Item	Reduction %	Ref.[2]
Potatoes (dehydr)	presoak & wash	surface contamination	0.5-12	(A)
Tomatoes	wash	soil	33-80	(B)
		organic debris	30-64	
		bacterial spores	6-79	
Tomatoes	wash	Drosophila eggs	10-70	(C)
Tomatoes	wash	bacterial spores	75-95	(D)
		lactic bacteria	75-96	
		mold	76-92	
Tomatoes	chlorinated wash	bacteria	90	(E)
Tomatoes	chlorinated wash	spores	92	992

1. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables," Western Research Laboratory, Berkeley, California, D-2459 (August, 1971).
2. References:
   (A) Lutz, J. M., Findlen, H., and Hanson, J., "Efficiency of Various Methods of Washing Red River Valley Potatoes," American Potato Jour. **32**:340 (1955).
   (B) Mercer, W. A., and Rose, W. W., "Studies on Tomato Washing Operations," National Canners Association Research Lab. Report No. 59-W-54, Berkeley, Calif. (1956).
   (C) Gould, W. E., Bash, W. D., Yingst, D. E., Geisman, J. R., Marlow, G. A., and Brown, W. M., "Handling and Holding Studies of Mechanically Harvested Tomatoes," National Canners Assoc. Information Letter No. 1909, Washington, D.C. (Jan. 31, 1963).
   (D) York, G. K., O'Brien, M., Winter, F. H., Tombropoulos, D., and Leonard, S. J., "Sanitation in Mechanical Harvesting and Bulk Handling of Canning Tomatoes," Food Tech., **18** (1): 97-100 (January, 1964).
   (E) O'Brien, M., York, G. K., MacGillivray, J. H., and Leonard, S. H., "Bulk Handling of Canning Tomatoes," Food Tech., **17** (8):1050-1055 (1963).

6. Peel, especially following chemical peelers.

The efficiency of removing various contaminants by washing potatoes and tomatoes has been reported; the results are summarized in Table 2.01.

Washing and rinsing operations are the major source of the hydraulic load associated with many products. The volume of water used for washing varies widely, not only from one commodity to another, but also within each commodity from one processing plant to another. Some reported quantities of water used (gallons per raw ton or gallons per finished case) and characteristics of the wastewater produced by washing fruits and vegetables are summarized in Table 2.02.

2.1121 Types of Washers

Washing methods vary according to the product. Commonly used washers include:

1. Sprays positioned over belts, elevators, or other conveyors.
2. Flood-type washers, consisting of immersion or soak tanks in which the product is moved forward by angled sprays and/or by recirculated water. Flumes are also used for washing in a similar fashion.
3. Rotary or reel washers, consisting of sprays situated within a perforated metal or screen cylinder.
4. Brush washers, consisting of revolving brushes which scour the exposed product surface.

Two or more types of washers arranged in series are generally most effective; various combinations are used for most commodities.

Spray Washers

Sprays are used extensively for washing raw products. They may be used exclusively or in conjunction with other types of washers. The primary function of sprays is to apply water in such a manner as to physically and efficiently remove undesirable materials from the raw product. Therefore, how water is used, as dictated by the type of spray nozzles and their physical arrangement, is most important; the quantity of water used is secondary.

Cleansing action of water is a function of the amount of energy imparted by the water on the raw product surface. Water impinging on a surface at a high velocity effects greater cleansing efficiencies than a large volume of water simply cascading onto the same surface. To obtain maximum cleansing efficiency of water used in spray washing equipment, careful consideration must be given to the choice and placement of spray nozzles.

1. Spray nozzles which deliver a small volume of water at high velocity are preferred; nozzles which deliver a flat, fan-shaped spray pattern are quite suitable and are most effective when arranged in banks (see Figure 2.03).
2. The nozzles should be of a design which minimizes clogging; this is especially important for sprays in recirculated water systems.
3. The discharge rate of the selected nozzle must be adequate to meet the needs of each particular application. The nozzles must be operated within the design water pressure range; operating pressures which are either too high or too low for the selected nozzles will decrease their effectiveness.

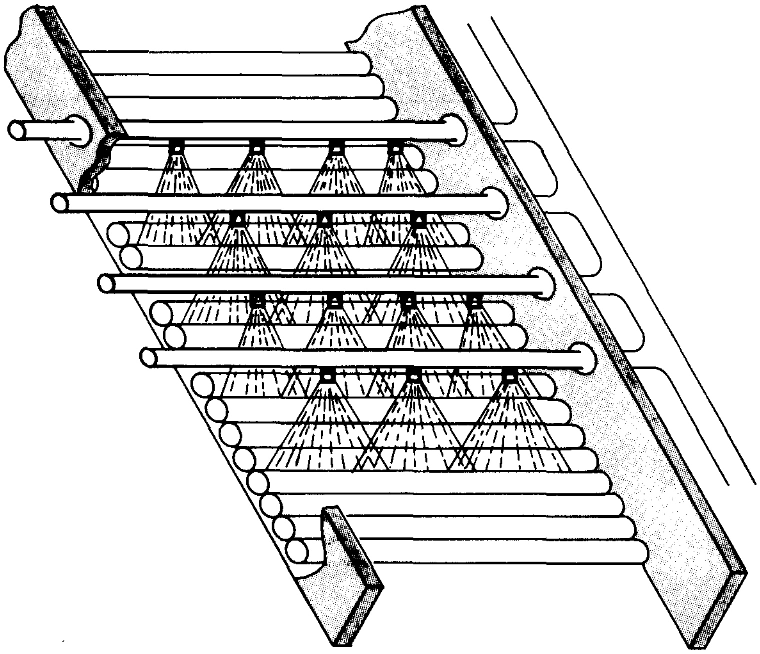

Figure 2.03. Spray washer with fan nozzles arranged in banks.

TABLE 2.02
USE OF WATER IN WASHING FRUITS AND VEGETABLES[1]

		Water Used		Effluent Load		
Product	Function	gal/ton[2]	gal/case[2]	BOD lbs/ton[2]	SS lbs/ton[2]	Ref.[3]
Beans, green	wash		25.5			(A)
Beets	primary wash flume	100		0.8	20.0	1048
Carrots	primary wash flume	90		0.5	2.0	1048
Corn	husked corn washer	103		2.5	1.0	1048
	washer & silker	212		15.0	4.0	
Cranberry	skimmer & washer	1440		36.5	15.0	224
Fruits	spray	385				813
Peaches	spray	360 (gal/min)				689
Peaches	lye peel rinse	707 (gal/min)				834
	flume	1028 (gal/min)				
Peas	clipper mill & wash	706		12.0	5.5	1048
	wash	432		4.0	0.5	
Potatoes	spray	2500		20.0	30.0	157
Potatoes	spray & soak	640		10.7	21.0	537
	peel & wash	468		2.2	2.2	
Potatoes	spray	960		5.1	2.7	745
Potatoes (dehydr)	slicer-washer	1540		40.0	49.7	765
Potatoes	primary wash flume	70		0.5	2.0	1048
Tomatoes	wash	1320				(B)
Tomatoes	rinse after dump	1186				834
	lye peel removal	504				
Tomatoes	spray		712			1026
	lye peel rinse		1374			
	lye peel rinse		790			

1. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables," Western Research Laboratory, Berkeley, Calif., D-2459 (August, 1971).
2. Ton of raw product or case of finished product.
3. See Guide to Literature on Waste Management.
   (A) Cook, R. W., *et al*, "Changes in Water Quality Factors During Recycling through a Water Recovery System While Canning Green Beans." National Canners Association, Washington Research Lab. Report No. 1-69 Washington, D.C. (1969).
   (B) Mercer, W. A., "Comments on Lagooning as a Method of Cannery Waste Disposal," National Canners Association (1958).

4. If the nozzles are positioned too high above the product, energy in the water will be partially dissipated and a less effective job of cleaning will result.
5. The nozzles must be spaced along each header so that the sprays do not overlap excessively, thereby resulting in excessive use of water.
6. The nozzles on the ends of each header should not be placed so widely as to cause waste of unused water along the sides of the washer.

The type of conveyor used in spray washing equipment influences the cleansing efficiency. Roller conveyors are most effective; the revolving rollers turn the raw product, thereby exposing all surfaces to the sprays while permitting leaves, stems, and other debris to be flushed through the rollers. The conveyor of second choice is constructed of steel-mesh belting; belting with the largest permissible openings should be used. Use of solid belting should be avoided in spray washing equipment.

One of the problems in washing is the unavoidable variation in amount of product going over a line, depending on the heaviness of deliveries from the field. Regardless of whether the line is loaded heavily or lightly, the washers operate with the same amount of water. Under constant conditions of water flow such as these, the cleanliness of the washed product is directly related to the quantity of product per unit volume of water. Wherever possible, the rate of product throughout should be as even as physically possible and held at that rate which yields maximum cleaning efficiency.

In some situations, consumption of water for spray washing and rinsing can be minimized by dividing the spray headers into two sets (see Figure 2.04). Fresh water is used initially through the final set of nozzles. This rinse water can then be collected and pumped to the first set of nozzles, thereby reducing the total volume of water by half. The wash water may be discharged as wastewater or may be collected and used for other purposes (see Section 2.12, In-plant Reuse

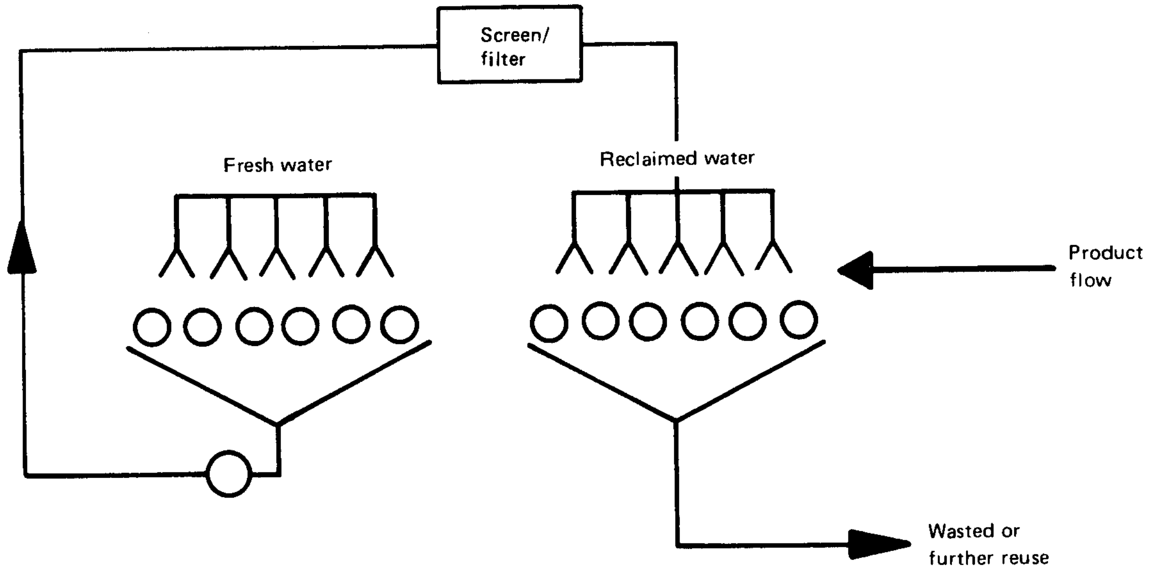

Figure 2.04. Reuse of final rinse water.

of Water). This arrangement is especially effective when sprays are used in conjunction with others types of washers or as a final rinse prior to canning or freezing.

The results of NCA studies on product washers emphasize the importance of the final spray wash. It is here that the final cleanliness of the product is established. Fluming and soaking are only a preparation for the final wash. The use of proportionately large volumes of water in tanks or flumes does not lessen the need for a vigorous spray wash.

Flood Washers

Flood-type washers include dump tanks, immersion tanks, flumes, and flotation washers. These are especially suited for washing leaf vegetables, easily bruised fruits, small particles such as peas and dry beans, and soil-encrusted mechanically harvested tomatoes. Cleansing is achieved by agitation of the product in water; this action is normally created by recirculating water within the unit. Sand, stones, and other settleable materials are removed periodically through bottom drains or continuously by constant water flow or mechanical means, depending upon equipment design. In flotation washers leaves, stems, and other floatable materials are either skimmed from the water surface or discharged from the unit by a constant overflow. Recommended procedures for handling these materials are discussed in Section 2.3, In-plant Handling of Solid Wastes.

In all flood washers soils and other suspended matter are flushed from the unit by the constant addition of clean water. Product cleansing dictates that the rate of clean water addition be sufficient to prevent build-up of contaminants within the system; water conservation and waste reduction dictate the rate be carefully adjusted to prevent excessive use of clean water.

Washing efficiencies are greatly enhanced when sprays are used to rinse the raw product as it is conveyed out of a flood-type washer. An arrangement similar to that depicted in Figure 2.04 is recommended. Effluent from the rinse sprays may be used in the flood washer to further the use of water (see Section 2.12, In-plant Reuse of Water).

Reel Washers

Reel washers are revolving cylinders of perforated metal, screening, or metal rods. Such washers are suited for cleaning root vegetables, as well as a variety of fruits and other vegetables. Generally, reel washers are tailored to handle specific products. Cleansing action is facilitated by the raw product units rubbing against each other as they tumble through the reel. A row of spray nozzles placed within the cylinder provides water to lubricate the raw product and to wash away soil and other extraneous debris.

Since the cleansing efficiency of reel washers is dependent upon the use of water, proper selection of spray nozzles is important. High pressure nozzles, either with fan-shaped or solid cone patterns, are recommended; they are most effective and use less water than flood-type nozzles. To maximize cleansing, attention must be given to the height and spacing of the nozzles within the reel. Product feed rates should be constant; overloading must be avoided.

Brush Washers

Brush washers are suitable for scrubbing root vegetables, especially if the vegetables have been previously soaked; the bristles effectively remove mud from the product surface. Asparagus is also cleaned with this equipment.[1] The brushes must be cleaned continuously with water sprays to prevent recontamination of the product.

Minimum water usage requires selection of suitable spray nozzles. High pressure, low volume nozzles are recommended.

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[1] Mercer, W. A., Rose, W. W., Regier, L. W., and Chapman, J. E., "Better Washing of Asparagus to Improve Quality and Prevent Spoilage," National Canners Association Research Laboratories, Western Branch, Report No. 60-W-46 (Feb. 17, 1960).

These should be positioned over the brushes to aid in cleaning the raw product while cleansing the bristles of mud and other debris.

Combination of Washers

Most commodities will require washing by a combination of two or more methods, such as soaking and flood washing, or soaking and reel or brush washing. Washing or rinsing operations may also be required at several intermediate points in the processing line, such as after peeling or cutting.

For all washing and rinsing operations, cleaning efficiencies must not be equated to the quantity of water applied, but rather to the method in which water is used. In every case a spray rinse will greatly enhance product cleanliness. Careful consideration and proper installation of spray nozzles, as previously discussed, will contribute significantly toward maximizing washing efficiencies while minimizing water consumption.

2.1122 Wash Water Temperature

Washing efficiencies are greatly enhanced when warm water (up to 140°F) is used. However, warm water may detrimentally affect the quality of some raw products. Furthermore, warm temperatures (above 80°F) are favorable for multiplication of food spoilage organisms.

Cold water is recommended for use in immersion washers (dump tanks, soaking tanks, flumes and flood washers). When bacteriological contamination is of concern in such systems, chlorination may be employed. Only that rate of clean water addition which will maintain an aesthetically acceptable condition within the system will thus be required.

Warm water may be used to wash raw products if appropriate precautions are observed.

1. Since the organic matter contained in the wash water will provide a good medium for bacterial growth, the wash water should be discharged as wastewater after use.
2. Chlorination becomes less effective with higher temperatures. When warm water is used in immersion washers, dilution by a high rate of clean water addition must be provided to control microbial populations.

2.1123 Use of Detergents

Detergents aid in the removal of soil and other debris from surfaces by increasing the wetability of the contaminants. The effectiveness of detergents is generally increased by using warm water. Detergent baths are effective for washing such products as root vegetables, asparagus, and mechanically-harvested tomatoes. The quantity of water required to rinse presoaked commodities will be substantially less when detergents are used in the soaking tanks.

Detergent formulations are widely varied; many are manufactured for specific applications. Only those detergents which have been approved by the Federal Food and Drug Administration for use in food processing operations must be used. Adequate rinsing must follow the application of detergents to assure that no residue is carried into the final product.

2.113 PRODUCT CONVEYING

Methods which are used to transport raw commodity within the plant can be classified into four general categories: manual, mechanical, hydraulic, and pneumatic. Except for limited situations, technological development of food processing plants has eliminated in-plant manual handling from all except visual inspection operations whereby culls and blemished pieces of commodity are removed. Pneumatic conveying systems are relatively recent developments. Mechanical and hydraulic conveying systems are most widely used. In the following discussions emphasis is placed on reducing waste loads emanating from these systems.

2.1131 Mechanical Conveying Systems

Mechanical conveyors in widespread use include belts (both solid belting and steel-mesh), vibrating or oscillating conveyors, live rollers, buckets, screws or augers, and drags. The type of conveyor used is limited by the nature (dry, fluid, whole, cut, etc.) of the commodity being handled; hence, the quantity of water used and the waste loads generated in relation to the different types of conveyors vary accordingly. Although water usage by mechanical conveying systems is normally minor, care must be exercised to prevent these systems from becoming significant sources of waste loads.

Screw conveyors are most frequently used to transport dry materials, such as flour and granulated sugar, or solid waste materials. In either situation, buildup of bacterial populations is not of urgent concern. Water usage is generally limited to cleanup operations. Drag conveyors are used most frequently to transport whole product from delivery areas into the plant or to transport solid residuals away from the processing areas. Again, water usage is generally limited to periodic cleanup. In these situations waste loads can be minimized by using high pressure-low volume cleaning equipment (see Section 2.116, Plant Cleaning).

Belts, vibrating or oscillating conveyors, live rollers, or bucket conveyors are used at numerous points within all plants. Since these are used to transport raw product in various states of preparation, sanitary considerations are of primary concern. To maintain an acceptable degree of equipment sanitation, water is generally applied continuously. As in the case of raw product washing, the degree of cleanliness is determined more by how water is used rather than by the quantity of water that is used.

Continuous cleaning of conveying equipment is normally accomplished with sprays. Maximum efficiencies can be obtained by using high pressure - low volume spray nozzles and water which has been chlorinated to 5 ppm. Since a continuous application of water is not generally required to maintain acceptable sanitary conditions, the quantity of water used can be significantly reduced by intermittant use of the cleaning sprays. Cleaning cycles can be controlled manually or by use of an appropriate timer and solenoid valves.

In addition to sanitation requirements, belts and oscillating conveyors may require a small volume of water for surface lubrication. Fogging nozzles, or other low volume mist sprays, can be advantageously used for this purpose. Use of chlorinated water, if practicable, will further retard bacterial growth and reduce the required frequency of cleaning.

2.1132 Hydraulic Conveying Systems

In-plant handling of raw products in hydraulic systems – pump and pipe systems and flumes – is now widely practiced in fruit and vegetable processing plants. Hydraulic conveying systems offer the advantages of gentle product handling, additional washing of commodities, less space for vertical transport, and ease of maintaining equipment sanitation. The major disadvantages are the relatively large volume of water required and the significant organic load generated by these systems.

The organic load associated with water in hydraulic conveying systems results from the washing and leaching of soluble organic matter from the commodity being transported. The organic matter is leached from the commodity because of the osmotic difference between the transport medium and the product tissue; the quantity of organic matter (the organic load) is a function of the duration of immersion and the size of the particles. The longer a piece of product is in water, the more material will be leached into the water; smaller particles provide greater exposed surface areas resulting in more rapid loss of solubles. Test results[1] depicted in Figure 2.05 demonstrate the effect of immersion time and particle size on the organic load, as measured by TOD (total oxygen demand, an instrumental measure of the concentration of organic matter present in water).

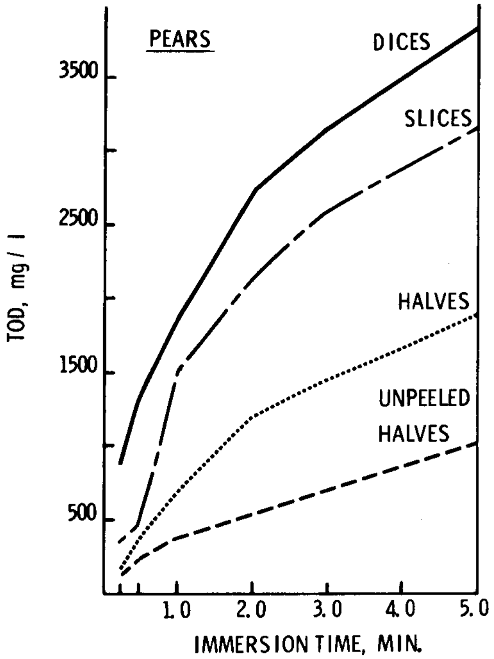

Figure 2.05. Laboratory result of pear leaching study.

Until osmotically equivalent fluid systems can be developed, there is little which can be done to significantly reduce the organic loads associated with hydraulic conveying systems. However, wastewater volumes from these systems can often be reduced simply by judicious use of water within each system. The following points should be considered:

1. Water in hydraulic conveying systems should be recirculated or reused, rather than discharged after a single use.
2. Fresh water additions to recirculating systems must be carefully adjusted to the minimum rate required to maintain acceptable sanitary and/or aesthetic conditions within the system and to maintain water temperatures below 80°F.
3. Wherever feasible, previously used water should be used in hydraulic conveying systems (see Section 2.12, In-plant Reuse of Water).
4. Fresh water must never be used to transport solid wastes.

Buildup of bacteria within some systems can be prevented (see Section 2.23, pH Control of Recirculated Water), thereby extending the usability of water within the system and effecting further reductions in water consumption and wastewater loads.

2.1133 Pneumatic Conveying Systems

Among the many recent innovations in food processing technology designed to curtail water pollution, pneumatic conveying systems offer a means to significantly reduce waste loads associated with the processing of several commodities. Where hydraulic conveyors have been replaced by pneumatic systems, both the hydraulic and organic loads have been markedly diminished. Pneumatic systems may be designed to convey materials by either positive or negative air pressure. Such systems offer the additional advantage of requiring very little floor space. A typical negative-air system is illustrated in Figure 2.06.

Although most types of solid wastes can be readily handled, pneumatic systems are currently able to satisfactorily handle only certain types of raw commodities. Limitations are imposed upon the size and density of the material to be transported, the distance, and the ability of the material to withstand rough handling without incurring physical damage. Commodities which are being successfully conveyed in pneumatic systems include peas, green beans, cut corn, lima beans, and carrots.[1] Solid wastes from numerous commodities are being handled pneumatically (see Section 2.3, In-plant Handling of Solid Wastes).

2.114 PEELING

Peel is removed from fruits or vegetables by one method or a combination of several methods, including hydraulic pressure, immersion in hot water or caustic solution, exposure to steam, mechanical knives, abrasion, hot air blast, exposure to flame, and infrared radiation. The more extensively used procedures for peeling root crops include abrasion, steam and abrasion, and immersion in a caustic solution followed by hydraulic or abrasive peel removal. Commonly used procedures for peeling fruits include mechanical knives and immersion in a caustic solution followed by spray rinses.

Peeling methods have been compared on the basis of the percentage of the trimming loss of the product rather than from the standpoint of water economy. Geneticists have expended much effort in the development of varieties (particularly vegetables) with thin smooth skin, absence of rootlets, and other desired conformation in order to reduce peeling losses. Nevertheless, peeling operations are major contributors to the total plant waste load. Reported characteristics of

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[1] Katsuyama, A. M., "Waste Generation and The Dollar Costs" in *Proceedings of the 1971 Research Highlights Meeting (D-2490)*, National Canners Association, Berkeley, Calif. (Nov. 1971).

[1] Wolford, E. V., "Negative Air Pressure Conveying", *Food Technology, 26* (2):37-41 (February, 1972).

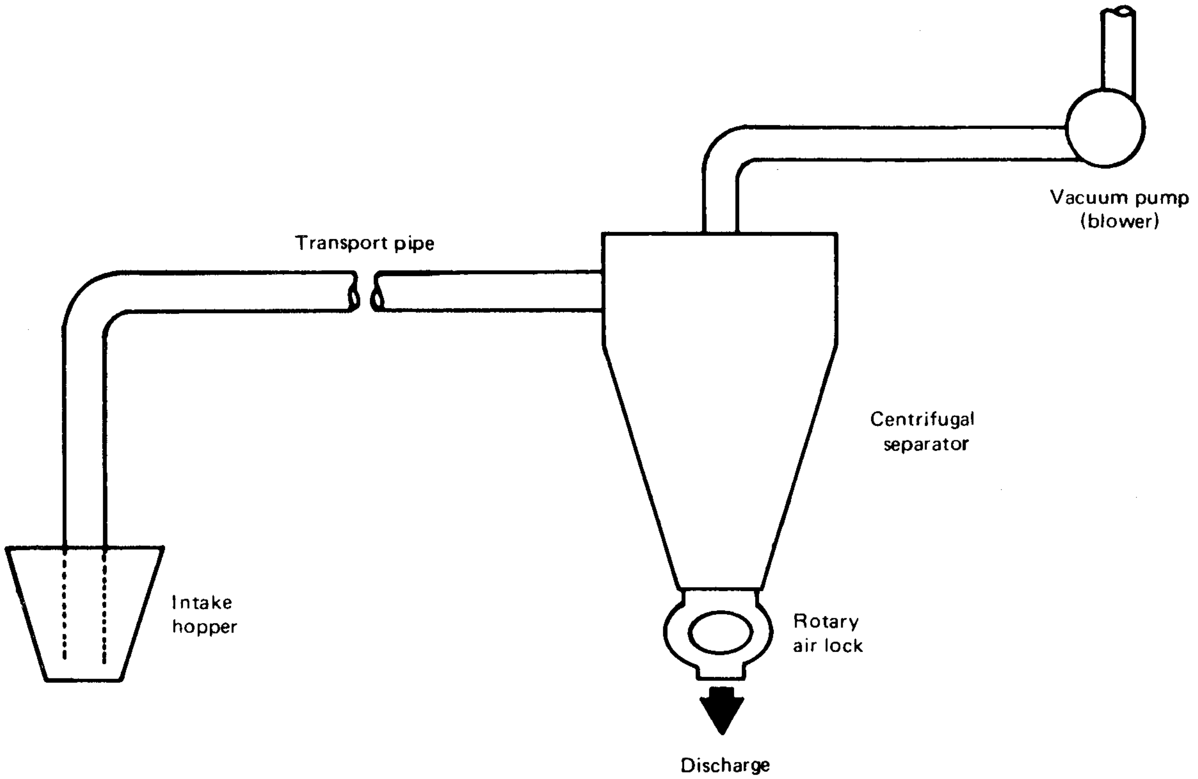

Figure 2.06. Diagram of a negative-air conveying system.

wastewater from fruit and vegetable peeling operations are summarized in Table 2.03.

Measures to readily reduce waste loads from peeling operations are limited. Except where abrasive peelers or mechanical knives are used exclusively, peeling operations are conducted in two steps – softening of the product skin, followed by physical removal of the peel material. Waste reduction measures in these two areas depend entirely upon the equipment in use. Because of the wide variety of peeling equipment currently being used, the following general comments are offered solely to serve as guides for implementing waste reduction programs for specific situations.

2.1141 Abrasive Peelers

Abrasive peelers, especially when used in combination with a skin softening procedure, require constant cleaning. Sprays are generally used to flush peel material from the peelers. Minimum waste loads and maximum cleaning efficiencies can be achieved by using high pressure-low volume spray nozzles for this purpose.

Whenever possible, the peel material should be collected and handled separately from wastewater (see Section 2.3, In-plant Handling of Solid Wastes). By preventing the peel material from entering the wastewater stream, soluble organic matter will not be leached into the water and significant reductions in the organic load can be realized.

Product leaving an abrasive peeler is relatively clean, having been effectively washed in the peeling process. When rinsing is desired, a minimal quantity of water should be used, as discussed in Section 2.112, Product Washing and Rinsing. Use of high pressure-low volume spray nozzle is recommended.

2.1142 Mechanical Knife Peelers

Mechanical knife peelers, as well as coring machines, require a constant application of water for lubrication and cleaning. Normally the volume of water used for this purpose is minimal. However, the peel and core materials may be major contributors to the organic load. Where solid wastes from these equipment are being hydraulically conveyed, significant reductions in the waste load can be realized by replacing the hydraulic systems with belt conveyors or other dry handling systems. By handling solid wastes in a manner precluding water contact, much of the soluble organic matter contained in the peel and cores will be prevented from leaching into water.

2.1143 Hot Water and Steam Peelers

Hot water and steam (both atmospheric and pressure) peelers, as well as flame peelers, serve to soften the product skin and outer tissues, thereby facilitating removal of peel material in a subsequent step. Waste loads from hot water tanks can be minimized by limiting fresh water addition to only that which is required to maintain the necessary volume within the unit. Waste loads from steam peelers can be minimized by limiting the steam injection rate to that required to accomplish the specified task; condensate from these units can be minimized by preheating the product entering the steam chamber.

Further waste load reductions are achievable in the peel removal step. Water is most commonly used to wash the peel material from the commodity. Here again, high pressure-low volume spray nozzles will more efficiently perform this task (see Section 2.112, Product Washing and Rinsing) – flood-

TABLE 2.03

CHARACTERISTICS OF WASTEWATER FROM PEELING FRUITS AND VEGETABLES[1]

	BOD			SS		
Product	lbs/ton[2]	lbs/cs[2]	% of plant waste stream	rate	lbs/cs[2]	Ref.[3]
Apricots	5-10					(A)
Beets (blancher/peeler)	194	4.0	84	220 lb/hr	1.0	1048
Carrots (blancher/peeler)	97	1.4	65	163 lb/hr	.7	1048
Peaches (rinse after peeling)			40			1026
Peaches	60 (COD)			10 lb/ton		(B)
Peaches	8-12			5-9 lb/ton		(A)
Pears	12-18			10-15 lb/ton		(A)
Potatoes (lye peel)	186	3.1	89		.5	1048
Potatoes (dry caustic peel)	26		80			(C)
Peach/tomato (rinse after peel)		.29	20			1026
Tomato (scald/trim)		.16				641
Tomato (lye peel)		.30				1026
Tomato (lye peel)		.12	35			1026

1. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables" Western Research Laboratory, Berkeley, Calif. D-2459 (August, 1971).
2. Pounds of BOD or suspended solids per ton of raw product, per case of finished product, or per hour of operation.
3. See Guide to Literature on Waste Management.
   - (A) NCA data, 1969.
   - (B) National Canners Association, " Low Water Volume Peeling of Peaches, Pears, and Apricots for Reduced Liquid Waste Volume and Strength," NCA Research Foundation, with EPA & USDA, Agr. Res. Service, Program 12060 FQE, Report D-2400 (June, 1971).
   - (C) Graham, R. P., *et al* "Dry Caustic Peeling of Potatoes" *Food Technology, 23*(2):195 (1969).

type nozzles which require large volumes of water are not recommended. Substantial reductions in the hydraulic load can be achieved by recycling the wash water (see Section 2.12, In-plant Reuse of Water). As an example, the experience of one processor is cited below.

Special water saving equipment is being used in conjunction with a steam peeler at a potato dehydrating plant. The unit consists of a tank or catch basin fitted with a perforated trough containing a screw conveyor. Water from the peel removal washer is collected in the trough. The water passes through the perforations into the tank and the peel material is retained in the trough and discharged by the auger. The water is then strained and pumped to the washer spray nozzles, thereby creating a closed loop system. An auxilary fresh water spray is positioned directly over the tank to serve a twofold purpose, surface foam suppression and makeup water supply. Water consumption for the peeling operation has been reduced by more than half by this equipment.

2.1144 Chemical (Caustic) Peelers

A wide variety of fruits and vegetables are peeled with the aid of caustic solutions. Caustic soda will soften or dissolve the outer tissue of many products, thereby enabling removal of peel by simply washing the treated commodity. The two steps of this procedure involve wastewaters of different characteristics which pose separate and unique disposal problems.

Caustic Solutions

Products which are chemically peeled are either immersed in or are sprayed with a caustic soda solution. Although most of the peel material is removed in the washer, some of this material will inevitably be deposited in the caustic tank. When the sludge concentration within the tank reaches a point which begins to interfere with peeling efficiencies, the caustic solution must be discharged.

Batch discharges of caustic solution must be avoided. These solutions are not only highly alkaline, but also contain high concentrations of organic matter. "Slug" doses of such materials are detrimental to all biological treatment systems and will cause "upsets" of systems which may otherwise operate well. To eliminate the detrimental effect of caustic solutions on wastewater treatment systems, holding tanks should be provided for the temporary storage of the spent caustic. The solution can then be metered from the holding tan,, thereby spreading the discharge over a period of time and obtaining a high dilution of the alkali with the plant effluent.

Caustic peeling efficiency, as determined by the effectiveness of peel removal and product yields, is related to the concentration of the solution, the temperature, and the duration of immersion of the product. (Peeling of tree fruits and tomatoes is enhanced by adding wetting agents to the caustic solution.) Careful consideration must be given to maintaining optimum conditions for each product being processed. Excessive peeling will result in increased loss of product (which will add to the organic load of the wastewater); insufficient peeling will require more extensive hand trimming and thereby add to the cost of production.

The volume of caustic solution in the tank should be maintained at a level which will prevent losses due to overflows. The usefulness of a batch of caustic can be extended by removing peel material—screens can be effectively used for this purpose—or by periodically pumping accumulated sludge from the bottom of the tank. Any measure which reduces caustic consumption will also reduce waste loads from chemical peeling operations.

Wash Waters

Caustic peeling washers are often the greatest single contributor to both the hydraulic and organic loads from a food processing plant. Large volumes of water, applied through high pressure sprays, are required to remove the peel material and residual caustic; the peel material is largely in a soluble or finely divided state. Comments pertaining to raw product washing (see Section 2.112) are also applicable to caustic peeling washers.

Caustic peeling washers normally contain several rows of spray nozzles. (High pressure-low volume spray nozzles are recommended over flood-type nozzles.) The hydraulic load from these washers can be reduced by up to 50% through reuse of water. The water applied initially to the commodity removes the major portion of the peel and residual caustic; the water applied to the commodity at the discharge end of the washer serves primarily to rinse the product. By dividing the washer sprays into two sets, fresh water usage can be limited to the final rows. The water can then be collected and reused in the initial rows where water quality is not critical. When rotary washers can be used, advantage can be taken of the abrasive tumbling action to which the product is subjected. Effective peeling can be achieved with less water whenever physical means can be employed to remove peel.

Reducing the organic load from chemical peelers requires major process changes. Since the organic load from chemical peelers is due to the soluble and finely divided peel material, reductions can be achieved only by withholding these materials from the effluent waste stream. Equipment has been recently developed whereby the peel material from white potatoes can be removed with reduced product loss and considerably less water than by the normal caustic or abrasive procedures, while substantially reducing the organic load.[1]

The system, called the "dry" caustic peeling process, utilizes a conventional caustic bath. The potatoes are held briefly after immersion in the caustic solution and are then passed under infrared heaters. The heat facilitates caustic penetration while drying the outer surface of each potato. The peel material and residual caustic are removed as a thick paste by specially designed rotating rubber discs; the pasty material is collected in a tank and pumped to a solid waste hopper, thereby preventing its incorporation into the wastewater effluent. The potatoes are given a light rinse to remove residual peel and caustic and are then processed in the normal manner. In one study, during which this system was compared to a conventional abrasive peeling system, water usage was determined to be 64% less; the pounds of BOD, 73% less; the pounds of suspended solids, 90% less.[2]

The rubber disc peel remover has been adapted for peeling beets and peaches on a commercial scale, and for apricots, pears, and other commodities on a trial basis.

2.115 BLANCHING

Blanching of vegetables for canning, freezing or dehydrating is conducted to achieve one or more of the advantages of product cleaning, inactivation of enzymes, degasification, color preservation, texture optimization, and precooking. Vegetables are blanched in hot water or in a steam atmosphere. Blanched vegetables are normally cooled prior to further preparation. Therefore, the cooling step is considered an integral part of the blanching operation.

Although water requirements for the blanching step are generally low, the process extracts a sufficient amount of soluble organic solids from the product to render effluents from the operation major contributers to the total organic load. This is especially the case with water blanching. Waste loads in effluents from vegetable water blanchers are summarized in Table 2.04; the suspended and total solids content in the effluents are summarized in Table 2.05. Additionally, the extent to which water can be recycled in the cooling step

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[1] Graham, R. P., Huxsoll, C. C., Hart, M. R., Weaver, M. L., and Morgan, A. I., Jr., "Dry Caustic Peeling of Potatoes," *Food Tech., 23* (2):195 (February, 1969).

[2] "An Investigation on the Effect of Dry Caustic Peeling on Potato Chip Wastewater Characteristics (Project No. F7349.0)," CH_2M/Hill, Corvallis, Oregon.

TABLE 2.04

POLLUTION LOADS IN EFFLUENTS FROM WATER BLANCHING OF VEGETABLES[1]

Vegetable	Effluent flow gal/hr	BOD lbs/ton	COD lbs/ton	SS lbs/ton	Ref.[2]
Beets (& peeler)	13,100	194 (85)[3]	323 (83)	239 (55)	1048
Carrots (& peeler)	8,420	97.6 (65)	196 (67)	338 (64)	1048
Corn	270	610 (lbs/day)	860 (lbs/day)	144 (lbs/day)	640
Corn	2,272	24.6 (16)	30.1 (18)	6.0 (12)	1048
Peas	1,280	3,500 ppm in effluent			671 533
Potatoes	2,520	52	58	37	745
Potatoes	2,310	22	32	25	745
Potatoes (& peeler)	9,210	186 (89)	279 (86)	181 (37)	1048

1. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables," Western Research Laboratory, Berkeley, California, D-2459 (August, 1971).
2. See Guide to Literature on Waste Management.
3. Percent of total effluent pollution load in parentheses.

TABLE 2.05
SUSPENDED AND TOTAL SOLIDS IN BLANCHER EFFLUENTS[1]

	Effluent flow	SS		TS	Ref.[2]
Vegetable	gal/hr	ppm	lbs/hr	lbs/hr	
Beets (& peeler)	13,100 (51)[3]		122	2,510	1048
Carrots (& peeler)	8,420 (49)		104	478	1048
Corn	2,272 (14)		28.2	206.4	1048
Peas		1,114			97
Peas		3,244			97
Peas	4,360 (20)		10.8	262	1048
Potatoes					
hot blanch	1,800	3,300			745
wet blanch	5,400	195	37 (per ton)		745
Potatoes & peeler)	9,210 (44)		70.1	3,330	1048

1. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables," Western Research Laboratory, Berkeley, California, D-2459 (August, 1971).
2. See Guide to Literature on Waste Management.
3. Percent of total effluent in parentheses.

is limited by temperature; therefore, the cooling step can be a major source of wastewater. Measures to readily reduce waste loads from blanchers are limited. However, the following considerations may assist to minimize these wastes.

2.1151 Blancher Water

The effluent from a steam blancher is due primarily to steam condensate. Although the BOD concentration may be quite high, the volume is generally minimal. Therefore, the total pounds of BOD are not great. For this reason steam blanchers are recommended for all products which can be satisfactorily blanched in this manner.

When water blanchers are preferred, consideration must be given to minimizing the total volume of wastewater discharged from the units.

1. The rate at which fresh water is added to the system must be reduced to an absolute minimum.
2. The organic load contained in blancher waters may impose "shock loads" on a biological treatment system if discharged in large batches. To avoid overloading waste treatment systems, blancher water should be discharged into temporary holding tanks and metered into the plant effluent over an extended period of time.
3. If blancher water can be isolated from the general plant wastewater and separately discharged (such as by land disposal via tank trucks), the organic load contained therein will be excluded from the total waste load, thereby effecting a substantial waste reduction.

2.1152 Hydrocooling Water

When vegetables are cooled after blanching, water is most commonly used as the cooling medium. The cooling system may be either a flume or a spray washer. Since water used for hydrocooling must be maintained at relatively low temperatures, water in the cooling system is generally discharged after a single use or is recycled with a high replacement rate. Although the BOD concentration of the cooler effluent is low, the volume is quite large. Therefore, both the organic and hydraulic loads from hydrocoolers are significant if discharged directly to waste.

Despite being somewhat warm, the quality of water from hydrocooling is more than acceptable for use in other operations. By recirculating the water within the hydrocooling system, relying on fresh water makeup for temperature control, and by reusing the effluent from the system elsewhere in the plant, the total hydraulic load of the plant effluent can be substantially reduced. Water reuse schemes and their effects on waste reduction are discussed in greater detail in Section 2.12, In-plant Reuse of Water.

2.1153 Alternative Procedures

Alternatives to conventional blanching are being investigated. The most promising are hot-gas blanching and individual quick blanching (IQB) methods. These have been tested on a limited variety of products with pilot equipment.

A recently developed cooler offers a means to virtually eliminate the use of water. This unit, which takes advantage of the natural phenomenon of evaporative cooling, consists of a vibratory conveyor fitted with a perforated plate situated over an air plenum (Figure 2.07). As the blanched product is introduced to the unit, air blown into the plenum rises up through the perforations and creates a fluidized-bed of product within the trough. The air assists in conveying the product and induces evaporative cooling. Water is applied to the product through fogging nozzles, thereby providing the water of evaporation while minimizing dehydrative losses. The product is cooled to ambient temperature during the time it travels the few feet of the conveyor length. Wastewater volumes from this unit are minimal.

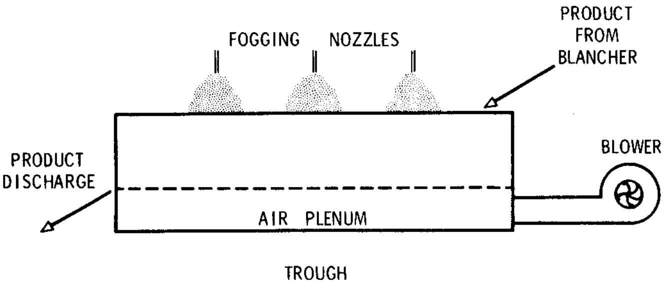

Figure 2.07. Diagram of an evaporative cooler for blanched vegetables.

2.116 PLANT CLEANING

Maintenance of cleanliness in a food plant may require frequent or continuous cleanup in addition to that at the end of each shift. Large volumes of water are often used to wash processing equipment, inspection tables, conveyors, walls, floors, and drains. Water is also used for cleaning areas outside the plant and for washing trucks, storage vats, produce conveyors, bins, platforms, and other equipment.

Continuous in-plant cleaning operations are conducted to keep wastes from accumulating during the operating day, thereby improving sanitation and reducing the time required for end-of-shift cleaning. In continuous cleaning wastes may be brushed from equipment or washed away with water. The dry method is recommended whenever practicable to reduce the amount of solids carried away in water. Dry cleaning procedures are discussed in detail in Section 2.3, In-plant Handling of Solid Wastes.

To maintain adequate cleanliness in a food plant with minimum use of water, careful consideration must be given to the design and construction of individual pieces of equipment. Recommendations proffered by the Special Committee on Sanitation of Canning Equipment are outlined in the NCA Laboratory Manual[1], to which the reader is referred. The following discussion is limited to those procedural practices which influence the generation of waste loads attributable to plant cleaning operations.

2.1161 Preliminary Steps

The contribution to the organic load by small fragments of product cannot be overestimated. As described later (Section 2.231) large amounts of soluble organic matter are washed or leached from the product whenever water is applied. To reduce the organic load attributable to cleanup operations, cleanup periods must be initiated by sweeping spilled material from the floors. The quantity of water then required to finish the cleanup operation will be substantially less.

This is evident when one observes plant employees where water is used exclusively during cleanup periods – how much water is expended to chase a few fragments several feet across the floor to the nearest drain!

Secondly, the use of mechanical (brushes, scrapers, squeegees) and chemical (detergents) cleaning aids, when properly used, can greatly reduce the time and increase the efficiency of cleanup operations. The quantity of water required for cleaning may be significantly reduced by using cleaning aids, especially when foods or other contaminants tenaciously stick to equipment surfaces. Cleaning aids are also discussed in detail in the above-cited section of the NCA Laboratory Manual.

2.1162 Water Hoses

When continuous cleaning is practiced, care must be especially taken to avoid wasting water from unattended hoses. Hoses should be equipped with automatic shutoff valves to save water and to avoid spraying the rest of the plant. To maximize the effectiveness of water, the valve outlets should be constructed so that nozzles of various types can be connected rapidly. The following interchangeable nozzles are suggested: a small jet type for cleaning deep cracks, a fin type for cleaning flat surfaces, a bent type for cleaning around and under equipment, and a spray head-brush combination type for cleaning surfaces where combined brushing and washing is needed.

2.1163 Special Cleaning Equipment

The cleaning efficiency of water is influenced by the temperature and the pressure under which it is applied. Hot water applied under high pressure is generally most efficient, thereby requiring smaller volumes to accomplish specified tasks. Numerous cleaning devices are available whereby water can be heated, pressurized, and, if desired, mixed with cleaning chemicals at controlled rates. Such devices are available as portable units which may be used in various areas within a plant or as stationary units with high pressure lines piped to various outlet stations.

2.1164 Cleanup Procedure

To minimize waste loads generated by cleanup operations, the following general procedure is recommended:

1. Dismantle or open all equipment as far as practical.
2. Brush, sweep, and shovel all solid wastes into containers.
3. Use pressurized hot water, with detergents and brushes if necessary, to remove material adhering to equipment surfaces, walls, and floors.
4. Rinse equipment with low pressure cold water.
5. Use squeegees or brushes, followed by high pressure, low volume cold water, to clean floors.

2.12 In-Plant Reuse of Water

In the early years of the canning industry, reuse of water in food plant operations was discouraged because of problems with bacterial contamination and subsequent spoilage of cans. Before the development of effective water chlorination procedures any reuse of water in contact with the product or for can cooling was considered to be hazardous.

Even now, the recovery of water from one processing operation for reuse in the same or another operation requires consideration of the effect of this water-saving procedure on the quality of the final product, on general sanitation of the plant, and especially, consideration of the effect on the sanitary condition of the unit operation in which the water is to be reused. Where chlorination of the reused water is relied upon to prevent bacteriological problems, the capabilities and limitations of chlorine, as a germicide, must be understood (see Section 2.22, Chlorination).

Once water has been used in an operation, it will no longer meet the standards for potability as defined by the U.S. Environmental Protection Agency. Fortunately, this does not preclude the reusability of water in food processing operations. Section 110.80 of the Food and Drug Administration's "Good Manufacturing Practices (GMPs)," which became effective on May 26, 1969, states:

> Water used for washing, rinsing, or conveying of food products shall be of adequate quality, and water shall not be reused for washing, rinsing, or conveying products in a manner that may result in contamination of food products.

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[1] National Canners Association, "Food Plant Cleaning", from *Laboratory Manual for Food Canners and Processors*, vol. II, pp. 138-158. The AVI Publishing Co., Westport, Conn. 1968.

To assure that reclaimed water can be used in compliance with GMP regulations, the water must meet the following conditions:

1. The water must be free of microorganisms of public health significance.
2. The water must contain no chemicals in concentrations toxic or otherwise harmful to man.
3. The water must be free of any materials or compounds which could impart discoloration, off-flavor, or off-odor to the product or otherwise adversely affect its quality.
4. The appearance of the water should be aesthetically acceptable.

Reclaimed water can be used in one of two ways; it can either be reused within the system from which it was recovered (i.e., recirculated) or it can be used in some other operation. Its suitability for use in any operation is dictated by the quality of water required in that operation. The final operations will require water of high quality, while water quality requirements are less stringent for intermediate and preliminary steps. Water used to convey waste materials can virtually be of any quality aesthetically acceptable. A check list indicating some potential uses of water from various unit operations is provided in Table 2.06.

TABLE 2.06

WATER-ECONOMY CHECK LIST

Operation or Equipment	May Recovered Water be Used?	May Water From This Equipment Be Reused Elsewhere In Plant?	Source of Water for Reuse in Equipment*
1. Acid dip for fruit	Yes	No	Can coolers
2. Washing of product			
A. First wash followed by 2nd wash	Yes	Yes*	Can coolers
B. Final wash of product	No	Yes*	
3. Flumes			
A. Fluming of unwashed or unprepared product (peas, pumpkin, etc.)	Yes	Yes*	Can coolers
B. Fluming partially prepared product	Yes	Yes*	
C. Fluming fully prepared product	No	Yes	
D. Fluming of wastes	Yes	No	Any waste water
4. Lye Peeling	Yes	No	Can coolers
5. Product-holding vats; product covered with water or brine	No	No	
6. Blanchers - all types			
A. Original filling water	No	No	
B. Replacement or make-up water	No	No	
7. Salt Brine quality graders followed by a fresh water wash	Yes	Only in this equipment	
8. Washing pans, trays, etc.			
A. Tank washers - original water	No	No	
B. Spray or make-up water	No	No	
9. Lubrication of product in machines such as pear peelers, fruit size graders, etc.	No	Yes*	Can coolers
10. Vacuum concentrators	Yes	In this equipment after cooling and chlorination	
11. Washing empty cans	No	No	
12. Washing cans after closing	Yes	Yes*	Can coolers
13. Brine and syrup	No		
14. Processing jars under water	Yes	For processing	Can coolers and processing waters
15. Can coolers		Water from these coolers may be reused satisfactorily for cooling cans after circulating over cooling towers, if careful attention is paid to proper control of replacement water, and to keeping down bacterial count by chlorination and frequent cleaning.	
A. Cooling canals			
1. Original water	No		
2. Make-up water	Yes		
B. Continuous cookers where cans are partially immersed in water			
1. Original water	No		
2. Make-up water	Yes		
C. Spray coolers with cans not immersed in water	Yes	This water may be reused in other places as indicated.	
D. Batch cooling in retorts	Yes		
16. Cleanup purposes			
A. Preliminary wash	Yes	Yes*	Can coolers
B. Final wash	No	No	
17. Box washers	Yes	No	Can coolers

*A certain amount of water may be reused for make-up water and in preceding operations if the counterflow principle is used with the recommended precautions.

Several methods whereby water may be recovered and reused are described in detail in this section. Since water reuse offers the most practical means to significantly reduce hydraulic waste loads, implementation of suitable reuse systems is strongly recommended.

2.121 WATER RECIRCULATION SYSTEMS

The use of water in some systems may be extended by recirculating the water in a cyclic, or closed-loop, fashion. Once such systems are filled, water consumption will be limited to the volume required to maintain a proper level or acceptable water quality within the units. To enable reuse of water in this manner, treatment procedures may be required. Generally, this disadvantage will be more than offset by the benefits accrued through reduced water usage and wastewater generation.

There are three principal areas or operations which readily lend themselves to water recirculation. These are (1) can cooling or freezer compressor cooling waters, (2) raw product fluming water, and (3) product concentrator or evaporator water. Although only these are discussed in the following, the principles and procedures which are described may be applied to other special situations.

2.1211 Cooling Waters

Can cooling water. Water is used to cool containers after thermal processing. To prevent the possibility of spoilage due to recontamination, chlorination of can cooling water is recommended (see Section 2.2244, Cooling Water Chlorination). Regardless of the type of cooling equipment used, the water must be continuously replaced to maintain the proper temperature to accomplish the designated task. A constant overflow of relatively clean, albeit warm, water results. If the temperature of this effluent stream is reduced, the water may be reused to cool additional containers.

Cooling towers are being successfully and advantageously used to reduce the temperature of cooling waters. When cooling towers are so used, the following precautions should be observed:

1. *Chlorination.* Sufficient chlorine should be added to the water after it has passed over the tower to maintain a residual of approximately 0.5 ppm at the end of the cycle. Since this amount is not adequate to prevent all growth of microorganisms, the chlorine residual should be increased to 4-5 ppm for a short time about every two weeks (see Section 2.2244).
2. *Screening.* It is advisable to screen all water before passage over the tower to remove any large pieces of foreign matter.
3. *Can washing.* All cans must be thoroughly washed, preferably with hot water, after closing and before entering the cooker, to prevent syrup, oil, or other adhering food material from contaminating the cooling water.
4. *Replacement water.* Sufficient replacement water should be added to prevent concentration of minerals (salts) to the point where spotting of containers becomes a problem.

Can cooling water may also be recovered and used in other operations, thereby reducing the total volume of water consumed by the plant. Can cooling water may be used directly in washers, or cooled and used for product rinsing or as make-up water in flumes. These reuse schemes are discussed in detail in Section 2.122, Counterflow Water Reuse Systems, and in Section 2.123, Special Water Reuse Systems.

Compressor cooling water. Although the volume of water used to cool freezer compressors may be relatively minor when compared to other effluent streams, the quantity annually consumed for this purpose is generally significant. The quantity of water required to cool compressors can be drastically reduced by collecting, cooling and recycling the warm effluent. Cooling towers can be advantageously used to lower the temperature of the water.

Since the compressor cooling water does not contain organic contaminants, only minimal chlorination of the water will be required prior to passage over a cooling tower. The primary purpose of chlorination is control of algae in the tower. The tower replacement rate may generally be limited to that which is required to maintain the necessary water level within the system. In situations where extremely hard water results in rapid and problematic concentration of salts, chelating agents may be used to minimize the volume of fresh water otherwise required for dilution.

2.1212 Product Fluming Water

The state of the raw product being conveyed largely determines the quality of water which is required in a flume (333). Flumes for conveying and washing raw products, such as beets, tomatoes, and other unprepared fruits and vegetables, do not require fresh water. On the other hand, partially prepared products, such as blanched vegetables and cut fruits, should be flumed in water of good sanitary quality. In all cases water may be recirculated in flumes provided that clean water, with or without chlorination, is added at a rate sufficient to maintain satisfactory conditions within each system.

Conservation of flume water in pea canneries, for example, has been accomplished by recirculating water within unit systems as illustrated in Figure 2.08. In the usual arrangement of such a system, the peas are fed into the hopper of an elevating pump for which water is supplied from a tank. At the end of the pump line the peas are discharged into a dewatering reel and are delivered to the next operation; the water is collected in a pan under the reel and returned to the supply tank. Usually the water is returned through the screen of a scavenger reel to remove larger solid particles. Fresh make-up water is added to the system continuously through an adjustable valve and intermittently upon demand through a float-controlled valve. The sanitary condition of the water is largely determined by the amount of fresh water added to the system.

An undesirable feature of recirculating flume water is the inherent tendency for developing relatively high concentrations of organic matter within the system. Each successive contact of the water with raw product adds to the organic content. Furthermore, the temperature of recirculated water tends to increase, thereby creating a favorable environment for multiplication of microorganisms; the resulting increase in spore loads aggravates the potential spoilage hazard for low-acid foods.

Buildup of particulate matter in a recirculated system can be minimized by incorporating a trash screen in the return line, as depicted in Figure 2.08. Carryover of bacteria from the system can be minimized by rinsing the product with fresh or clean water. The rinse water can be added to the system for make-up and/or dilution.

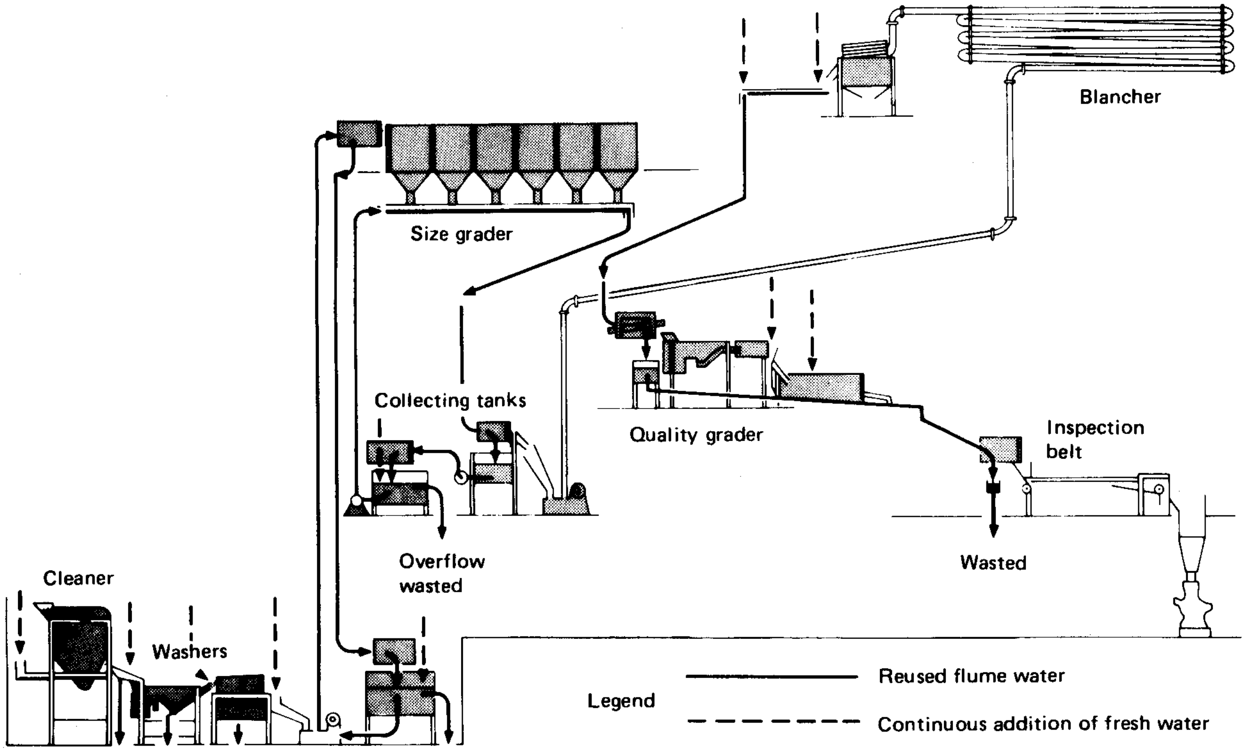

Figure 2.08. Diagram of water flow in a flume system (with recirculated water in two operations and reused water from a third operation to flume peas to the inspection belts).

Controlling the concentration of organic matter and bacterial numbers in recirculating flumes by dilution would require the addition of clean water at a variable but high replacement rate. Although this practice will greatly reduce wastewater volumes compared to single-use fluming systems, the resultant waste load will still be considerable. Waste generation and bacterial numbers can be more effectively controlled by counterflow reuse and chlorination of water (see Section 2.122, Counterflow Water Reuse Systems, and Section 2.2245, Chlorination of Water Reused for Other Than Cooling). When fluming peaches, apples and other high-acid products, bacterial numbers can be controlled with minimal dilution by controlling the pH of flume waters (see Section 2.23, pH Control of Recirculated Water).

2.1213 Evaporator Water

One type of evaporator widely used to concentrate tomato and fruit juices, fish solubles, and other food products employs a barometric leg to create a vacuum in the unit and to condense vapors emanating therefrom (Figure 2.09). Cold water injected into the barometric leg condenses water vapor and volatile organics while absorbing the heat of vaporization. Since the exit temperature of the water is one of the parameters which determine the efficiency of operation, cold water injection rates are closely controlled.

A multi-effect evaporator can consume a large quantity of water (in excess of 1,000 gpm). Because the effluent is warm (generally around 120°F.) and may contain traces of organic matter, the water is often wasted. However, this water is suitable for reuse. Since the effluent volume is large, cooling and recycling offer the greatest potential for reducing the wastewater volume. Cooling towers are being advantageously used for this purpose. Although the thermodynamics will differ, the application is similar to the recovery of can cooling and freezer compressor waters. Fresh water additions may be required to control concentrations of minerals and organic matter; the resultant overflow from the system can be readily used elsewhere in the plant.

2.122 COUNTERFLOW WATER REUSE SYSTEMS

Preparatory operations in food processing are designed to assure the delivery of clean, wholesome product to the final packaging operation. Water is used at various stages to separate and remove undesirable materials, such as leaves, soil, immature and overripe product, and finally, bacterial contaminants. To assure product cleanliness water used in final washing and rinsing operations must be of highest sanitary quality, whereas water used in preceding operations need not necessarily

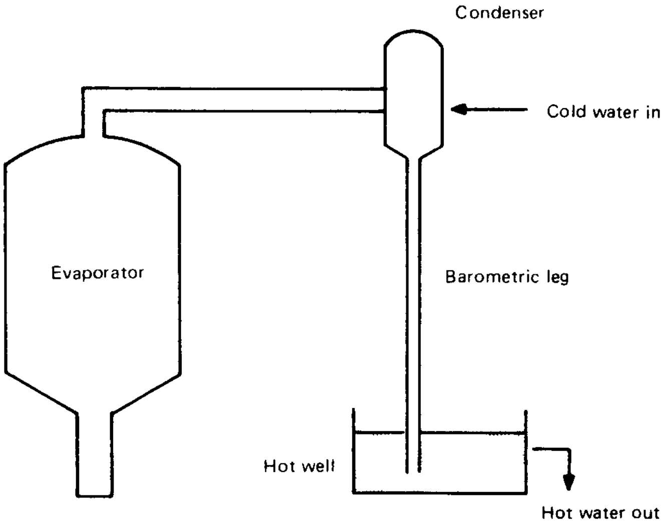

Figure 2.09. Barometric condenser of a multi-effect evaporator.

meet such stringent sanitary requirements. This premise is the basis upon which counterflow water reuse systems have been developed.

The sanitary condition of water is normally evaluated by measuring the bacterial population in the water (see Section 2.21, Determining the Sanitary Condition of Water). The sanitary condition of raw product is, of course, directly influenced by the bacteria count of the water with which it comes in contact (521). The condition of pea fluming waters was monitored during a study in which recirculation was compared to counterflow reuse with different chlorination practices; the results are summarized in Table 2.07. The comparative bacteria counts clearly indicate the effectiveness of product cleansing by counterflow reuse of water.

TABLE 2.07

COMPARISON OF TOTAL NUMBERS OF BACTERIA IN FLUME WATERS REUSED BY RECIRCULATION AND BY COUNTERFLOW METHODS, AND COMPARISON OF THE EFFECT OF VARYING THE EXTENT OF CHLORINATION IN THESE WATERS

Method of water reuse and extent of chlorination in each plant:

Plant A - Water recirculated; in-plant chlorination only.
Plant B - Counterflow reuse; no chlorination at any point.
Plant C - Counterflow reuse; in-plant chlorination only.
Plant D - Counterflow reuse; in-plant chlorination plus rechlorination.

Use of Water Sampled	Plant	Bacteria Count * per ml of Water		
		High	Low	Average
Water used to flume peas from quality graders to inspection belts	A	23,000,000	27,000	4,729,000
	B	350,000	13,000	65,200
	C	14,500	2,300	6,300
	D	3,500	400	1,300
Water used to pump or flume peas from blanchers to quality graders	A	1,800,000,000	590,000	365,590,000
	B	1,900,000	77,000	611,000
	C	220,000	14,000	58,760
	D	21,000	700	6,250
Water used to flume peas from size graders to blanchers	A	78,000,000	98,500	15,752,000
	B	2,900,000	50,000	837,200
	C	190,000	10,000	40,140
	D	130,000	2,300	22,470
Water used to flume peas from washers to size graders	A	52,400,000	91,000	13,752,300
	B	11,000,000	350,000	1,780,000
	C	130,000	14,000	47,180
	D	140,000	3,500	31,610

*Bacteria counts represent the numbers of colonies growing on glucose-tryptone agar plates inoculated with unheated flume water and incubated for 48 hours at 86°F.

Counterflow water systems are designed to minimize the quantity of water required to effectively prepare clean foods, thereby minimizing waste loads associated with food processing. Basically, most of the fresh water is used in the final operation, collected and reused in a previous operation, and recollected and reused in this manner one or more additional times. Since the water always passes counter to the flow of product, the product comes into contact with subsequently cleaner water and is finally washed or rinsed with fresh water. Although the following discussion concerns counterflow reuse in pea processing, the principles may be applied to the processing of any commodity.

2.1221 A Four-stage Reuse System

A general plan for counterflow reuse of flume water in a pea cannery is shown in Figure 2.10. In this plan most of the fresh water enters the system as flume water for conveying peas from the quality graders to the inspection belts; this is the final washing of the peas before they are filled into the cans. The water separated from the peas at the inspection belts is collected and used for the second time in fluming peas from the blanchers to the quality graders.

The water is used for the third time in fluming peas from the size graders to the blanchers, and for the fourth time to pump peas from the washers to the size graders. At the size graders the water is separated from the peas by means of a reel. From this point it may be used in the first washing of the peas or may be diverted to flumes which remove wastes from beneath the cleaners. Figures 2.11 and 2.12 show counterflow reuse schemes for different arrangements of equipment. (Figure 2.11 may be compared with Figure 2.08 to illustrate the differences between recirculation and counterflow reuse of water.)

In each case rechlorination of the water is recommended after each use. As indicated by the results summarized in Table 2.07, rechlorination will effectively reduce and control bacterial populations in reused water. Recommended procedures are outlined in Section 2.2245, Chlorination of Water Reused for Other than Cooling.

2.1222 Installation of Counterflow Systems

The amount of water which can be saved by a counterflow reuse system will depend primarily on the degree of balance obtained between the rate of fresh water addition to the system and the amount of water required to adequately carry out the different operations. If the system is to be water-saving, there must be no appreciable wastage of water other than that which may be required to maintain aesthetically acceptable conditions within the system. In order to obtain maximum benefits with minimum supervision, the system should include collection tanks, screens, and appropriate water valves.

Collection tanks. After each use the water should be collected in a tank from which it may be delivered by pump or gravity to the next operation. Ordinarily the water used in the same fluming operation on all of the canning lines should be brought into one collecting tank. For example, in Figure 2.10 all of the water used to flume peas from quality graders to inspection belts would be collected in Tank No. 1. It is important that water from a later stage in the reuse system not be added to this tank. The tank should have sufficient capacity to contain, without overflowing, all of the water which would be delivered to it when all lines are in operation.

Screens for reused water. To prevent the accumulation of particulate matter in reused water, fine mesh screens should be provided at each collection tank. Removal of particulates will extend the reusability of reclaimed water. Dry systems to collect and transport the accumulated solids should be provided (see Section 2.3, In-plant Handling of Solid Wastes).

Automatic valves for fresh water make-up. Fresh water lines, equipped with float-controlled valves, should be provided at each collecting tank. These valves will eliminate the

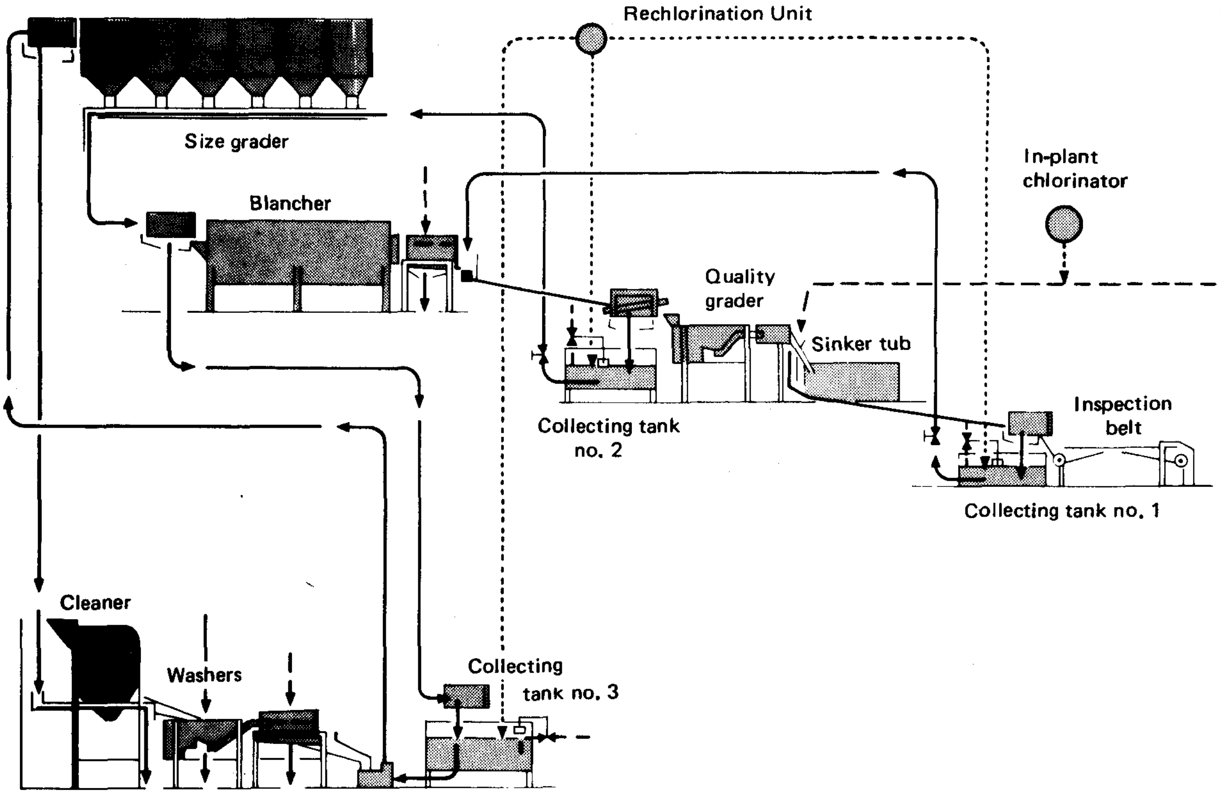

Figure 2.10. General plan for counterflow reuse of flume water in a pea cannery.

possibility of the tank becoming empty, thereby protecting the pump and assuring that an adequate supply of water is available for the subsequent operation.

Control of flow rates. Minimization of water usage by the counterflow reuse method depends entirely upon maintaining balances between the several component sub-systems. Water withdrawn from any collection tank must not exceed that volume which is required by the next operation, nor should the withdrawal rate from any collection tank greatly exceed the previously used water supply rate.

Careful planning is a definite prerequisite to successful implementation of counterflow reuse systems. Control of such systems will be facilitated by the use of variable speed pumps for adjusting all flow rates. Alternatively, gate valves, installed in the lines immediately after the pumps, can be used to regulate the water withdrawal rate from each tank to correspond to the water requirement in the next operation. In either case, periodic adjustments may be required to assure maintenance of appropriate balances and maximum efficiencies.

2.1223 Cooling and Washing Requirements

In the usual arrangement of the counterflow system for peas, the second use of water is for fluming or pumping peas from blanchers to quality graders. This fluming operation requires more careful attention than the other.

The peas are discharged from blanchers at an average temperature of 200°F and are covered with varying amounts of foam and blanch water high in organic solids. In some cases the blanchers may be contaminated with thermophilic flat-sour bacteria, the spores of which will be on the peas. If these peas are discharged into the flume while still hot, the sanitation of the third and fourth stages of the reuse system may be greatly impaired; warm water will favor rapid microbial growth which can cause excessive slime growth on equipment.

Of more serious consequence, however, is the increased potential for flat-sour spoilage in canned peas. Studies have shown that blanched peas not previously cooled before entering the flumes to the quality grader may reach the grader with a temperature still above 100°F. Elevated temperature in water which has a high concentration of organic matter will be favorable to the growth of thermophilic bacteria in the flumes. Furthermore, failure to adequately wash blanched peas can result in an accumulation of thermophilic spores in the quality grader brine.

Impairment of water quality due to factors attributable to blanchers can be prevented or greatly minimized by cooling and washing blanched vegetables in a separate operation. Equipment which can be used for this purpose, listed in the order of preference, include air coolers, vibrating screens with overhead sprays, reel washers, and hydrocooling flumes.

Sprays used with vibrating screens or reel washers should be supplied with cold, chlorinated water. Since the volume of water used by these units is relatively small, the wash water can be wasted without contributing significantly to the total plant effluent. Rather, water so used will enable more extensive reuse of the large volume of water in the counterflow system by minimizing heat input and by preventing excessive amounts of organic matter and bacteria from accumulating within the reuse system.

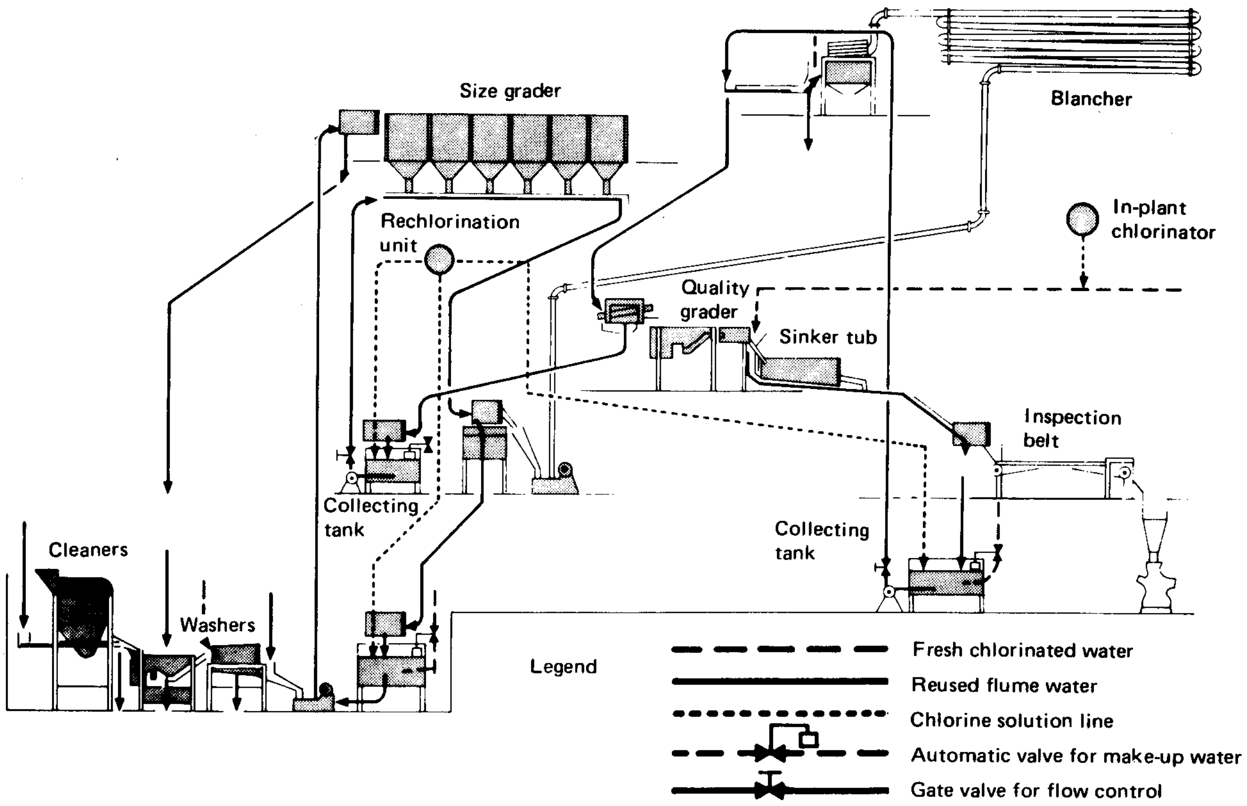

Figure 2.11. Plan of counterflow reuse system designed to eliminate undesirable features of flume system shown in figure 2.08.

2.1224 Water Saved

Under average conditions it has been estimated that the installation of a counterflow reuse system will reduce the total water consumption by approximately 50 percent of the volume which would otherwise be used if fresh water is used in all operations. However, the amount of water which can be saved by installing a counterflow system depends upon the unit operations within each plant. Estimations of potential water savings and waste load reductions can be made by surveying the processing plant and monitoring each wastewater flow. Procedures with which to accumulate pertinent data are described in Section 3.2, Mapping Plant Water and Waste Streams, and in Section 3.3, Methods for Measuring Flow.

2.123 SPECIAL WATER REUSE SYSTEMS

Variations in plant layouts, processing operations, types of equipment, and varying urgencies to conserve water and/or reduce waste loads, not to exclude variable waste characteris-

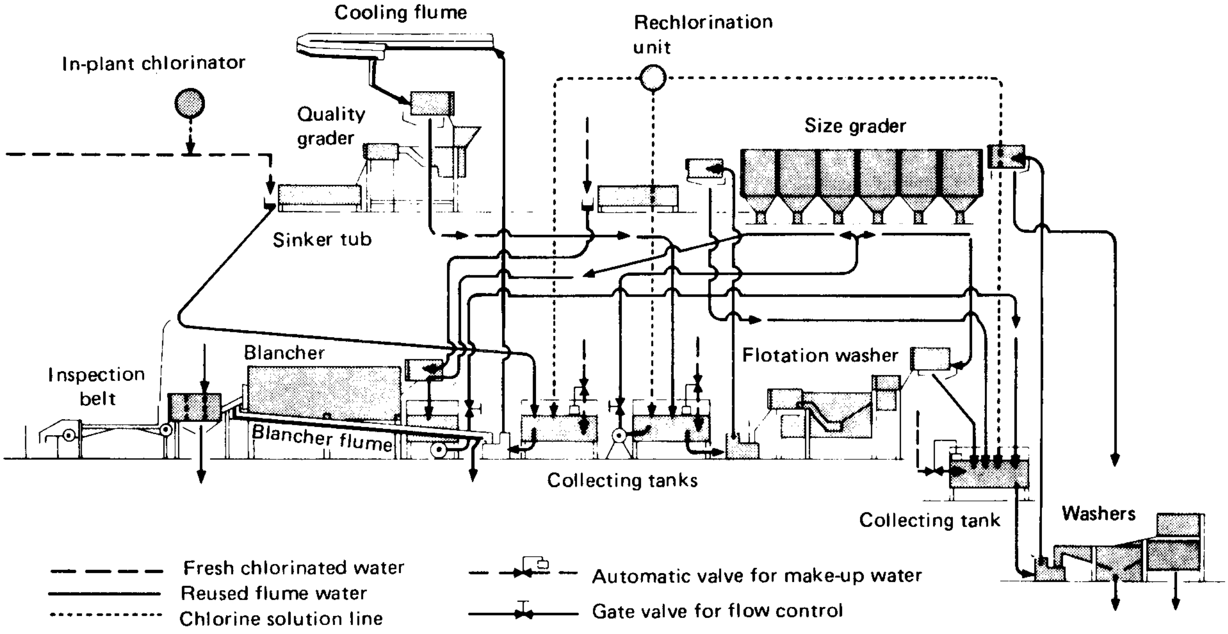

Figure 2.12. Plan for counterflow reuse of water in a pea cannery where line arrangements require extensive fluming operations.

tics, are but a few of the many reasons that detailed discussion of specific water reuse systems are of limited value. Instead, coverage of general principles which can be adapted to a variety of situations have been attempted in the preceding sections. However, some unique situations offer potentially wide-spread applicability for solution to common problems. For this reason, the following special systems are described.

2.1231 "Triple Duty" Water Reuse System

An advanced type of water reuse system in a specialty foods plant has recently been reported (958). This system has been designed to not only conserve water, but also to conserve heat energy. As depicted in Figure 2.13, the system consists of two parallel closed loops and a third open-ended leg.

The main feature of the closed loop circuits is the sterilization tank. Make-up water added to the system at this tank is recovered air compressor cooling water and condensate from cereal drum dryers and building heaters. The water is treated with ozone, pumped through a vertical cartridge-type filter, heated to 190°F in a shell-and-tube heat-exchanger, and supplied to the two closed loop systems.

Water in the first loop is used to wash empty jars. The wash water is collected in a sump, pumped through a filter, and returned to the sterilizing tank. In the second loop the water is used to fill retorts. Effluent from the retorts is collected in two separate sumps; water with a temperature above 150°F is collected in one, while water below 150°F is collected in the other. The hot water is filtered and returned to the sterili-

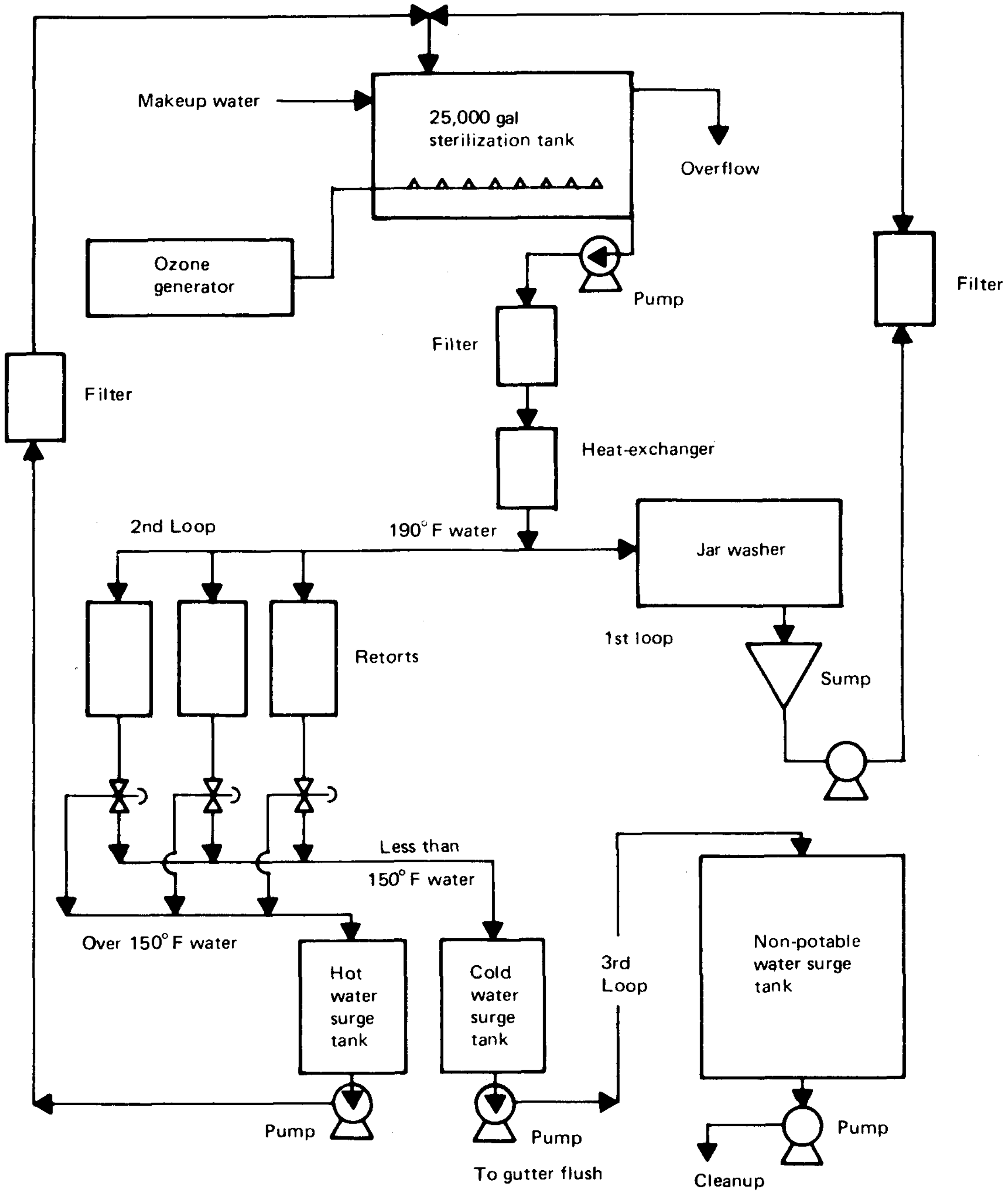

Figure 2.13. Advanced reuse system employing ozone sterilization.

zation tank, thereby completing the second circuit. By segregating and recycling only the hot water, less energy is required to reheat water from the sterilization tank, thus resulting in a conservation of heat and fuel.

Water below 150°F from the retorts is used in the final leg of the system. This water is used for flushing gutters and cleaning floors in processing areas and is discharged thereafter to waste.

2.1232 Sedimentation - Carbon Filtration Water Recovery System

A treatment and recovery system was designed to remove suspended and dissolved solids and to reduce the bacterial load from green bean processing wastewater.[1] A simplified diagram of the system is shown in Figure 2.14. The special feature of the water recovery operation is the sedimentation and carbon filtration treatment system which clarifies the used water sufficiently for recycling through the canning operations. (Individual components of the treatment system are described in Section 4.)

The water system. The water reservoir may be considered the starting point of the cycle. It is divided into two compartments, one containing 40,000 gallons of fresh water and the other a 20,000-gallon mixture of recovered and fresh water. In this way a supply of fresh water is readily available in the event of system malfunction. Air is bubbled through the recovered water compartment to increase dissolved oxygen. Chlorine in the form of hypochlorite is added periodically to the reservoir.

Water is pumped from the recovered water compartment to the first chlorinator where sufficient chlorine is added to give 1 ppm free residual. From the chlorinator, some water is sent to the rotary cooler of the continuous cooker and the remainder is sent to the can cooling canal. The water from the rotary cooler is spray cooled, filtered through sand, and added to the can cooling canal.

The water overflow from the cooling canal is used in three ways: for product washing after blanching, for initial product washing, and in the plant drains to carry out solid wastes. Water used for both product washing operations is combined with the plant drain water and channeled to the treatment area for screening. Particles larger than one-half inch are removed by passing the wastewater stream through a mesh belt conveyor; waste particles smaller than one-half inch are removed by a 48-mesh 60° tangential screen.

The screened wastewater is divided into three portions. One portion is pumped directly into the plant to flush the floor drains. Another portion is piped into the water recovery system. The remainder of the liquid waste is discharged.

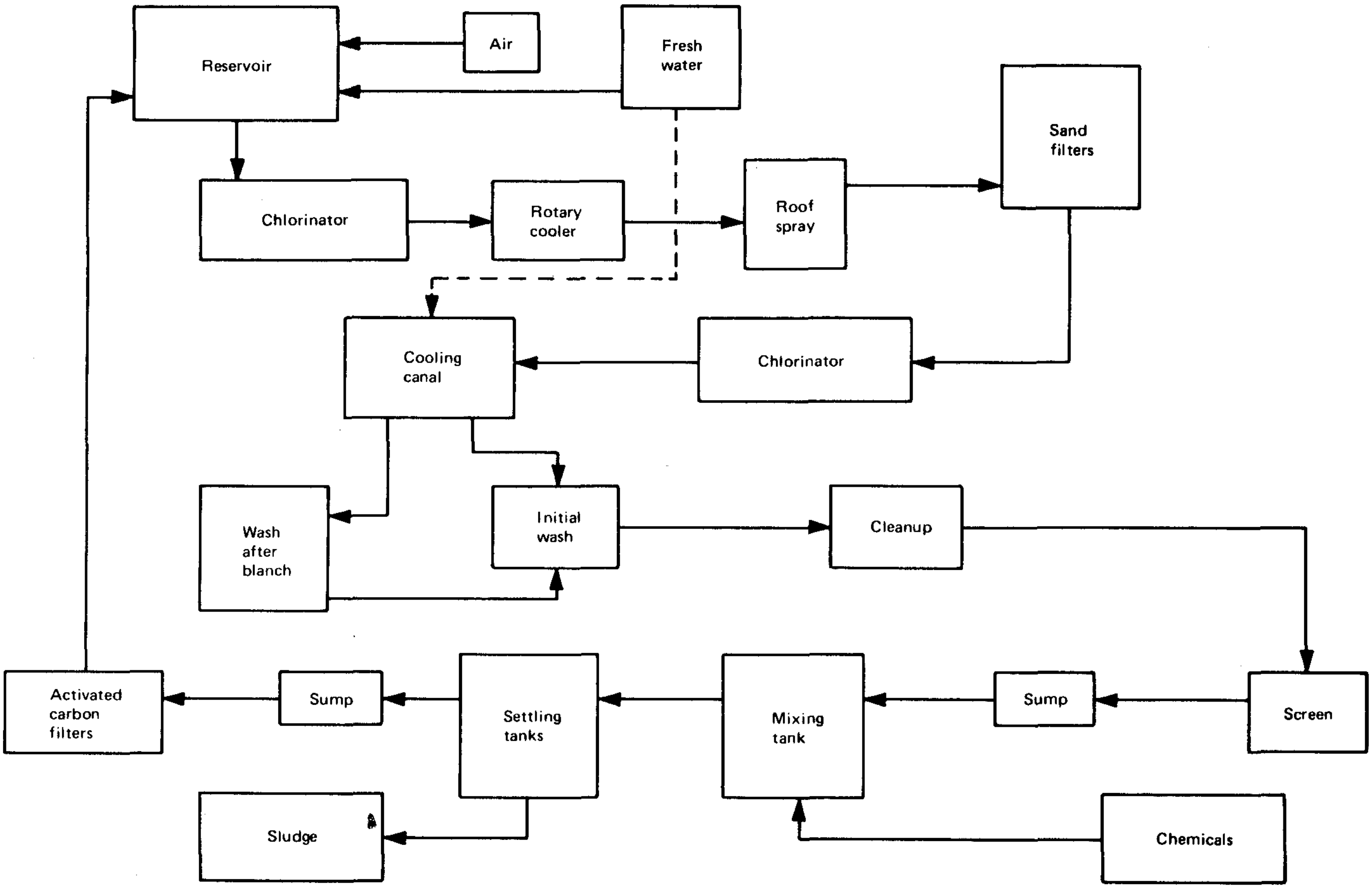

Figure 2.14. Diagram of charcoal filtration water recovery system.

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[1] Cook, R. W., Wang, J., Daughterty, P., Farrow, R. P., and Rhoads, A. T., "Changes in Water Quality Factors During Recycling Through a Water Recovery System While Canning Green Beans," National Canners Association, Washington Research Laboratory, Washington, D.C., Research Report No. 1-69 (March 1969).

The treatment system. The recovery system consists of coagulation, sedimentation, and filtration treatments. When operating properly, the system is designed to remove all traces of suspended matter, including colloidal particles. Under ideal conditions the filter effluent will be almost free of bacteria.

Caustic soda, aluminum sulfate, and a polyelectrolyte (flocculant aid) are added to the screened wastewater in a flash mixing tank. After a three minute detention period, the mixture is delivered to two flocculating tanks, each of which provides a ten minute detention. Air is injected into the tanks to provide agitation and facilitate flocculation. Flocculated solids are removed as a sludge from the settling tank and are discharged to a lagoon. The clarified water is filtered at the rate of 50 gpm through a five-foot bed of charcoal and is returned to the water reservoir.

Treatment results. The reduction in fresh water consumption achieved with the reuse treatment system is shown in Table 2.08. The recovery system resulted in an 18.4% reduction in fresh water consumption by the canning plant during the first year and a 25.4% reduction during the second year. The hydraulic loading on the waste disposal system was thus reduced by a corresponding proportion.

It should be emphasized that the data are derived from wastewater resulting from a single product operation, green bean canning. This water recovery system works well for this plant and for this particular product. Water from multiproduct operations may be more difficult to treat; each system should be considered individually. However, the results indicate that wastewater reclamation and reuse is feasible without undue risk of canned product spoilage.

TABLE 2.08

EFFECT OF WATER RECOVERY SYSTEM ON WATER USAGE IN CANNING GREEN BEANS

Date	Gals/Case Fresh Water only	Gals/Case using Recovered Water	Percent Decrease
8-7-67	22.9	16.4	28.4
8-9-67	26.5	18.2	31.3
8-11-67	32.9	22.2	32.5
8-29-67	27.2	20.3	25.4
8-31-67	24.3	19.3	20.6
Average	26.8	19.3	28.0
1967 Season*	25.5	20.8	18.4
1968 Season*	20.8	15.8	25.4

*For periods when recovery system were used.

2.2

MAINTAINING SANITARY CONDITIONS OF WATER

Water of good quality, suitable for human consumption, is a basic requirement in the canning industry. In food processing it is essential that effective methods be employed to safeguard the plant water supply against serious contamination by disease-producing bacteria and other deleterious substances. The National Interim Primary Drinking Water Regulations[1] offer a suitable guide for fresh water quality in the food canning and freezing industry.

In Table 2.09 are presented limits for certain physical, chemical and bacterial characteristics not to be exceeded in meeting quality requirements of water to be used by the canned, dried, and frozen fruits and vegetables industry.[2] The reader is referred to Section 3 of this Guide, as well as to *Standard Methods*[3], for analytical procedures to measure those parameters of particular interest to the industry.

Since bacteriological aspects of water are of primary concern to food processors, appropriate tests are discussed in this section. Present practices for maintaining sanitary conditions of water in food processing plants are also discussed, with particular attention to the use of chlorine as a germicidal or sanitizing agent.

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[1] *Code of Federal Regulations* (CFR), Title 40, Part 141 - National Interim Primary Drinking Water Regulations. (40 *FR* 59565, Dec. 24, 1975; amended by 41 *FR* 28402, July 9, 1976).

[2] "Water Quality Criteria." Report of the National Technical Advisory Committee to the Secretary of the Interior. Federal Water Pollution Control Administration, Washington, D.C. April 1, 1968.

[3] "Standard Methods for the Examination of Water and Wastewater" (14th edition). American Public Health Association, Inc., Washington, D.C. 1976.

2.21 Determining The Sanitary Condition of Water

2.211 TESTS FOR COLIFORM ORGANISMS

Coliform organisms are the main concern relative to drinking water quality. The primary groups of coliform organisms are *Escherichia coli (E. coli),* which characteristically inhabit the intestines of mammals and are indicative of fecal contamination, and *Aerobacter aerogenes,* which are soil organisms. The tests which are briefly outlined below are discussed in detail in *Standard Methods*[1] and in the NCA Laboratory Manual.[2]

2.2111 Presumptive Test

The Presumptive Test may be routinely used for regularly monitored water supplies. The multiple-tube fermentation technique is normally employed. This method requires the use of replicate tubes containing lactose broth or lauryl tryptose broth. The tubes are inoculated with the water being tested and incubated at $35^{\circ} \pm 0.5^{\circ}C$ for 24-48 hours. Gas production indicates the presence of coliform organisms. Results are expressed as the most probably number (MPN) of organisms per 100 ml of water, as determined from appropriate tables which appear in the above references. Positive results obtained by the Presumptive Test are not necessarily indicative of fecal contamination.

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[1] "Standard Methods for the Examination of Water and Wastewater" (14th edition). American Public Health Association, Inc., Washington, D.C. 1976.

[2] National Canners Association, "Laboratory Manual for Food Canners and Processors," The AVI Publishing Company, Westport, Conn. 1968.

TABLE 2.09

QUALITY REQUIREMENTS OF WATER AT POINT OF USE BY THE CANNED, DRIED, AND FROZEN FRUITS AND VEGETABLES INDUSTRY[1]

Characteristic	Limiting Values*
Acidity (H_2SO_4)	0
Alkalinity ($CaCO_3$)	250
pH, units	6.5-8.5
Hardness ($CaCO_3$)	250
Calcium (Ca)	100
Chlorides (Cl)	250
Sulfates (SO_4)	250
Iron (Fe)	0.2
Manganese (Mn)	0.2
Chlorine (Cl)	(a)
Fluorides (F)	1[b]
Silica (SiO_2)	50
Phenols	(c,d)
Nitrates (NO_3)	10[b]
Nitrites (NO_2)	(c)
Organics:	
Carbon tetrachloride	0.2[e]
Odor, threshold number	(c)
Taste, threshold number	(c)
Turbidity	(f)
Color, units	5
Dissolved solids	500
Suspended solids	10
Coliform, count/100 ml	(f)
Total bacteria, count/100 ml	(g)

* Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.

a. Process waters for food canning are purposely chlorinated to a selected, uniform level. An unchlorinated supply must be available for preparation of canning syrups.

b. Waters used in the processing and formulation of foods for babies should be low in fluorides concentration. Because high nitrate intake is alleged to be involved in infant illnesses, the concentration of nitrates in waters used for processing baby foods should be low.

c. Zero, not detectable by test.

d. Because chlorination of food processing waters is a desirable and widespread practice, the phenol content of intake waters must be considered. Phenol and chlorine in water can react to form chlorophenol, which even in trace amounts can impart a medicinal off-flavor to foods.

e. Maximum permissible concentration may be lower depending on type of substance and its effect on odor and taste.

f. As required by USPHS Drinking Water Standards, 1962.

g. The total bacterial count must be considered as a quality requirement for waters used in certain food processing operations. Other than esthetic considerations, high bacterial concentrations in waters coming in contact with frozen foods may significantly increase the count per gram for the food. Waters used to cool heat-sterilized cans or jars of food must below in total count for bacteria to prevent serious spoilage due to aspiration of organisms through container seams. Chlorination is widely practiced to assure low bacterial counts on container cooling waters.

Tests for the presence of coliform organisms, in determining acceptability of water under the National Interim Primary Drinking Water Regulations, require that only media and methods specified in the regulations be used. It is necessary in routine analysis using the multiple-tube fermentation technique that a minimum of five tubes be employed, each containing the chosen medium along with either 10 ml or 100 ml of the water sample. The absence of gas in all five tubes with 10 ml portions (less than 2.2 coliform organisms per 100 ml) is usually interpreted to indicate that the single sample meets the standards. In general, not more than 10 percent of the standard 10 ml portions examined each month, following the standard procedure, should show the presence of the coliform group. When 100ml portions are examined in the same manner, not more than 60 percent should contain organisms of the coliform group.

2.2112 Confirmed Test

The purpose of the Confirmed Test is to differentiate principally between *Escherichia coli* and *Aerobacter aerogenes* and other miscellaneous lactose fermenting organisms. Transfers are made from positive tubes in the Presumptive Test to fermentation tubes containing brilliant green lactose bile broth or to Endo or eosin methylene blue (EMB) agar plates. Gas production in the brilliant green lactose bile broth fermentation tubes after 48 hours of incubation, or the development of typical colonies on the EMB agar plates after 24 hours, constitutes a positive Confirmed Test for the presence of *E. coli.*

Organisms of the coliform group are considered to be reliable indicators of the adequacy of treatment. The presence of *E. coli* is indicative of dangerous and recent fecal contamination; the presence of other types of coliform organisms in treated drinking water suggests either inadequate treatment or access of undesirable materials to the water after treatment.

2.2113 Membrane Filter Technique

The membrane filter technique offers an alternative standard method for monitoring the bacteriological quality of potable water supplies. This method offers a high degree of reproducibility and makes possible the testing of relatively larger volumes of sample. Water is filtered through a suitable sterile filter membrane under partial vacuum. The filter is aseptically placed on a sterile pad containing a specified nutrient medium. After incubation the filter is examined under magnification for the presence of typical coliform colonies. Results are reported as number of colonies per 100 ml. Total coliform count or fecal coliform count may be directly obtained by selecting the appropriate nutrient medium.

2.212 STANDARD PLATE COUNT

The Standard Plate Count, although regarded as limited in value for routine fresh water analysis, offers a useful method for determining the general bacterial condition of foods and food processing operations. Procedures for obtaining total bacterial counts of liquid and solid samples and from surface areas are discussed in the NCA Laboratory Manual.[1]

Plate counts are obtained on glucose-tryptone agar incubated for 2 to 4 days at 30°C (or for 24 to 48 hours at 35°C). Results are reported as number of colonies per ml, number per gram, or number per square centimeter. The quantitative degree of contamination is comparative and therefore not precise. However, plate counts are useful in judging suitability of waters for reuse in various food processing operations and in determining the effectiveness of chlorination and other measures for maintaining the requisite sanitary conditions in canning and freezing plants.

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1. National Canners Association, "Laboratory Manual for Food Canners and Processors," The AVI Publishing Company, Westport, Conn. (1968).

2.22 Chlorination

Chlorination of water supplies has been employed for many years as a safeguard against waterborne disease. In recent years industrial water chlorination has become common practice in food processing plants to improve plant sanitation. Such practice also has become a requisite part of in-plant water recycling procedures for water conservation and for reduction of the amounts of wastewater requiring treatment and disposal.

2.221 CHLORINE AND ITS COMPOUNDS

Chlorine and chlorine compounds widely used in food processing water treatment are briefly described below. The chlorine content of various chlorine compounds are listed in Table 2.10.

Table 2.10

NAMES AND CHLORINE CONTENT
OF VARIOUS CHLORINE COMPOUNDS

Type of Compound	Common or Trade Name	% Total Available Chlorine
Low-test calcium hypochlorite	Chloride of lime Bleaching powder Chlorinated lime	30-35
High-test[1] calcium hypochlorite	Perchloron	70
	HTH	15-65[2]
	B-K	50[2]
Sodium hypochlorite	Purex and Clorox	Household = 2-6 Industrial = 10-18
Chloramines	Sterichlor	4
	Chloramine-T Dichloramine-T Azochloramide	Varies from 30 to 70
	Antibac	16

1. Pure lime chlorinated to a very high degree.
2. High test 70% hypochlorites are often diluted with Na_2CO_3 to yield 65, 50, 15 or other percentages of available chlorines. The higher the percent of sodium carbonate they contain, the less rapidly they deteriorate.

Gaseous Chlorine

Chlorine is prepared commercially by the electrolytic decomposition of sodium or potassium chloride solution. It can be used as a gas or as one of its compounds. Under ordinary atmospheric pressure chlorine is a greenish-yellow gas about two and one-half times heavier than air. Due to this greater density it will flow to the lower levels of a room or building. Chlorine is non-flammable and non-explosive. However, it reacts chemically with many substances and may cause a fire or explosion when in contact with combustible materials. In the presence of moisture it is very corrosive to common metals. Chlorine is only slightly soluble in water, the maximum solubility being about 1% at 49.2°F. As the temperature increases the solubility decreases until it is zero at the boiling point of water. Chlorine combines with water below 49.2°9F to form crystalline hydrates commonly called chlorine ice.

Liquid chlorine is shipped in steel cylinders or containers. Because of the incompressibility of liquid chlorine and its high rate of expansion on heating, a headspace of around 12% is allowed in all containers as a safety precaution. This headspace allowance will take care of expansion which may result up to a temperature of around 150°F.

Chlorine containers usually range from 100 pounds to 30 tons, or tank car, capacity. For industrial use where the daily requirements are less than 50 lb. per 24 hr., 150-lb. cylinders are suggested. At plants having greater requirements than this, there is generally an advantage in purchasing chlorine in 1-ton cylinders.

Hypochlorites

Calcium and sodium hypochlorites are extensively used for chlorination of industrial waters. Sodium hypochlorites are sold as liquids, while calcium hypochlorites are marketed in the powdered form. They are prepared by treating the respective alkali with chlorine gas; the degree of chlorination determines the percent of available chlorine. In the case of calcium hypochlorites, a tendency for the powders to cake is attributed to the impurities in the lime.

Minimum precautions must be taken when storing hypochlorites.

1. Containers for dry calcium hypochlorites must be tightly sealed and should be stored in a cool, dry place to avoid excessive loss of the loosely-combined chlorine.
2. Containers for sodium hypochlorite solutions should be non-metallic since these solutions are very corrosive to common metals.
3. Hypochlorite solutions should be stored in amber glass or crockery bottles to prevent decomposition by sunlight.
4. Powders must be kept in moisture-free places to avoid caking which will cause deterioration and loss of chlorine.

Chloramines

Chloramines, formed by the reaction of chlorine with ammonium nitrogen in an aqueous solution, are more stable and much less corrosive than the hypochlorites. Formation of chloramines is a reversible reaction, resulting in the formation of undissociated HOCl in low concentration when chloramine is dissolved in water.

Action of chloramines is slower but longer lasting than that of hypochlorites; they are particularly useful in situations where a long contact time is preferred. Their germicidal action is too slow, however, to be of much value for in-plant chlorination.

Other Chlorine Compounds

Chlorine in combination with other chemicals in addition to those previously mentioned has been used in producing other germicides. Various trade name materials are in this category. One of the more common products is made by replacing part of the water of crystallization of trisodium phosphate with chlorine. It has an available chlorine content of only 3 to 4%, but is more stable than hypochlorites. Since this product contains a phosphate, its germicidal efficiency is lowered by the alkalinity of the solution produced. Chlorine dioxide has been used to treat recirculated water. Effective bactericidal residuals have been reported for single-point rather than multiple-point application.[1]

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[1] Welch, J. L., and Folinazzo, J. F., "Use of Chlorine Dioxide for Cannery Sanitation and Water Conservation," *Food Tech. 13*: 179-182 (1959).

2.222 EXPLANATION OF TERMS

Terms which are commonly used in discussion of chlorination are briefly explained below.

Chlorine Dosage

The amount of chlorine added to water is often called the "chlorine dosage". This value is usually given in parts per million and is independent of the chlorine demand of the water.

Chlorine dosage expressed as pounds implies that the stated weight of chlorine has been added to water. When a hypochlorite is used, it is based on the pounds of available chlorine present in the hypochlorite solution.

Chlorine Demand

When chlorine is added to water, other than distilled water, a small amount, normally 0.25 to 0.75 ppm, reacts with impurities in the water. The amount reacting depends on the quantity and type of impurities present, the pH, the time of contact, and the temperature. The difference between the amount of chlorine applied (chlorine dosage) and the amount of residual present after reaction is known as the "chlorine demand" of the water.

Impurities responsibile for this demand include compounds containing iron, manganese, nitrites, and sulfides. Chlorine taken up by these materials no longer has germicidal properties and cannot be detected by the methods used for measuring chlorine concentrations.

When the chlorine demand of water is considered, it is always necessary to know the pH, the conditions under which the test was made, the temperature of the water and the time required to produce the first persistent residual. Usually, the chlorine demand is determined after 10, 15, or 20 minutes of contact time between chlorine and water (see Section 2.2268).

Total Residual Chlorine

The amount of chlorine remaining from a given dosage after the demand of the water has been satisfied is termed the "Total Residual Chlorine."

Free Residual Chlorine

Residual chlorine exists either as free chlorine or as chlorine which has loosely combined with nitrogenous matter to form chloro-nitrogen compounds. It is the free residual chlorine which gives the color in the orthotolidine flash test (see Section 2.2261). In aqueous solutions free chlorine exists as hypochlorous acid (HOCl), as the hypochlorite ion (OCl^-), or as a mixture of the two, depending on the pH of the water. The rate at which bacteria exposed to chlorine are killed is proportional to the amount of chlorine present as undissociated HOCl.

Combined Residual Chlorine

Chlorine which has combined with nitrogenous compounds in the water to form chloramines and/or other chloro-nitrogenous substances is called "combined residual" chlorine. Free residual chlorine and combined residual chlorine may exist in water at the same time. The total residual chlorine minus the free residual equals the combined residual chlorine. At pH 8.4 or above, the combined residual chlorine is present mostly as monochloramines (NH_2Cl), while at pH 4.5 and below, mostly di-chloramines ($NHCl_2$) are formed. Between these pH levels there is a mixture of mono- and di-chloramines.

Marginal Chlorination

Marginal chlorination is the addition of just sufficient chlorine to water to produce a residual which may be either free or combined depending on the amount of nitrogenous matter present. This level of chlorination usually destroys pathogenic organisms. For potable water with only low or moderate contamination, the following residuals are suggested:

1. In samples taken at the collecting tank following treatment, either 0.2 ppm for a sample having a chlorine contact time of 5 minutes or 0.1 ppm for a sample having a chlorine contact time of 30 minutes.
2. In samples taken at distant points in the distribution system, a residual of 0.05 ppm.

For heavily contaminated or reused water larger dosages are recommended. In the event of a threatened or actual outbreak of a water-borne disease, the chlorine residual should be increased to at least 0.2 ppm throughout the distribution system.

The principal objection to marginal chlorination is that water containing low chlorine levels may develop off-flavors due to incomplete oxidation of the nitrogenous matter. Since free residuals at low levels do not persist appreciably beyond the point of application, marginal levels are not of value for in-plant chlorination or for recycled water which requires a high level of free residual chlorine at the point of water use.

Break-Point Chlorination

When small amounts of chlorine are added to water under controlled conditions, the first increments of chlorine are used up in satisfying the chlorine demand of the water. At the same time, chlorine loosely combines with nitrogenous matter present to form chloramines or other chloro-nitrogen compounds. As additional chlorine is added a free residual appears. This residual gradually increases until it reaches a concentration, determined by the physical and chemical nature of the water, at which an oxidation reaction occurs between the free chlorine and the chloro-nitrogen compounds. The free chlorine residual is decreased by the amount necessary to completely oxidize the chloro-nitrogen compounds.

Further additions of chlorine beyond this point will result in a second rise in free chlorine concentration which increases almost in direct proportion to the rate of chlorine application. It is this persisting residual which makes in-plant chlorination of value. The point after the first rise in concentration at which the free residual reaches its lowest level is known as the "break-point" (see Fig. 2.15). Waters in which the chlorine addition does not reach the break-point may retain a high concentration of the chloro-nitrogen compounds. The presence of chlorine in certain of these compounds greatly intensifies their unpleasant odor and taste to produce the so-called chlorinated water flavor as observed in many municipal water supplies. Beyond the break-point, however, these odors and tastes are practically eliminated.

Chlorine dosage beyond the break-point has been used by some cities for disinfecting their water supplies. Referred to as superchlorination the chlorine concentration is increased to levels as high as 10 ppm, held briefly and then reduced by the

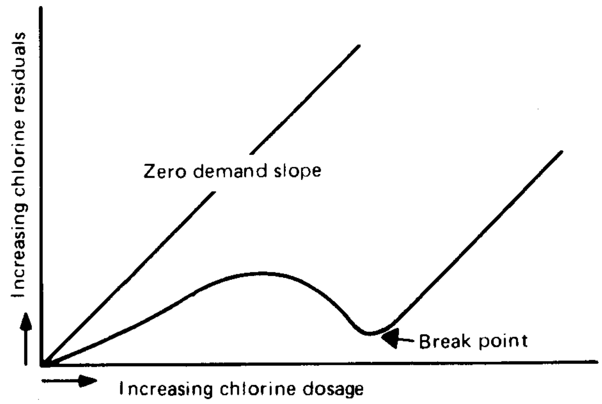

Figure 2.15. Break-point curve.

addition of activated carbon, sodium thiosulphate, sulfur dioxide or sodium sulfite. Although the chlorine will oxidize and degrade organics, its principal use is for the destruction of bacteria and other microorganisms (i.e., disinfection).

Not all waters exhibit the break-point effect. In those which do, many variations from the typical break-point curve may be determined. Surface waters from melting snow or sources practically free from chemical and organic matter, will show little, if any, evidence of a break-point. Its existence can be determined only by tests on each individual water supply (see Section 2.2267).

In-plant Chlorination

In-plant chlorination has been defined as break-point chlorination of all water as it enters the plant to such a degree that a good persisting residual occurs. This is generally in the range of 2 to 10 ppm.

2.223 CHLORINE AS A GERMICIDE

While several theories have been offered to explain the action of chlorine as a water microbicide, it is well established that when a water solution of this chemical comes in contact with microorganisms, death of the cells will result if the chlorine concentration is high enough and contact long enough. According to the most generally accepted theories, hypochlorous acid (HOCl) is considered to be the germicidal agent since the speed at which chlorine kills bacteria is directly proportional to the concentration of undissociated HOCl in solution. Hypochlorous acid is readily produced when chlorine and hypochlorites are added to water, but it is produced very slowly by hydrolysis when chloramines and similar compounds are added to water. This probably accounts for the difference in the relative germicidal effectiveness between chlorine and its various compounds.

Factors Influencing the Germicidal Activity of Chlorine

Factors which most directly influence the production of hypochlorous acid from chlorine and chlorine compounds are: (a) the chlorine concentration, (b) the pH of the solution, (c) the temperature of the water, and (d) the concentration and type of organic matter in the water.

Chlorine Concentration. It is generally true that the rate at which bacteria are killed is directly related to the concentration of chlorine in the water. Since chlorine reacts with water to form hypochlorous acid, the higher the concentration of chlorine the faster the bacteria are killed. This relationship is true only when the pH and temperature of the water remain constant.

Effect of pH. The equation for formation of hypochlorous acid is:

$$Cl_2 + H_2O \underset{OH^-}{\overset{H^+}{\rightleftharpoons}} HCl + HOCl$$

Under acidic conditions (lower pH) the formation of hypochlorous acid is maximized; as the pH is raised the amount of HOCl in solution is decreased. Thus anything which affects the pH of the solution will affect the HOCl concentration and, in turn, the germicidal effectiveness of chlorine.

Products formed when the various chlorine compounds are dissolved in water are important from this standpoint. When chlorine gas is added to water, hypochlorous acid (HOCl) and hydrochloric acid are produced as shown by the above equation. The HCl produced results in a decrease in pH and an increase in germicidal action. When calcium hypochlorite is added to water, hypochlorous acid, calcium chloride, and calcium hydroxide are produced as follows:

$$2\ CaCl(OCl) + 2H_2O \rightarrow Ca(OH)_2 + CaCl_2 + 2HOCl$$

$$Cl_2 + H_2O \underset{OH^-}{\overset{H^+}{\rightleftharpoons}} HOCl + HCl$$

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$$

Similarly when a sodium hypochlorite is added to water, hypochlorous acid, sodium chloride, and sodium hydroxide are formed.

The amount of HCl produced by the above reactions of hypochlorites is only sufficient to neutralize half the alkali formed, so that free alkali results. This free alkali raises the pH and in turn reduces the amount of HOCl produced, with the result that the germicidal power is lowered. This effect is clearly demonstrated by investigative results which are summarized in Table 2.11, showing that a sodium hypochlorite solution which contains 5 ppm total residual chlorine requires 2-1/2 times as long to kill all the yeast cells as does a 5 ppm chlorine gas solution. As the concentrationn of hypochlorites is increased, the pH increases. For example, a calcium hypochlorite solution of 25 ppm has a pH of 9.35, a 100 ppm solution has a pH of 9.75, and a 1,000 ppm solution has a pH of 11.10. At these high pH levels the concentration of HOCl produced in relation to chlorine dosage is greatly reduced.

In the concentration normally used, chloramines do not materially affect the pH when added to water. For this reason they may be preferred to hypochlorites for certain uses

TABLE 2.11
COMPARISON OF KILLING POWER OF HYPOCHLORITES AND GASEOUS CHLORINE

Chlorine Compound	Total Residual Chlorine (ppm)	pH[1]	Time Required to Kill 99.9% of Cells[2]
Chlorine gas	5.00	7.0	1 minute
Calcium hypochlorite	5.00	7.4	2 minutes
Sodium hypochlorite	5.00	7.6	2.5 minutes

1. The pH of the unchlorinated water was 7.2.
2. Test organism was a nonsporulating yeast.

where high concentrations are desired. However, the pH of the water does affect the hydrolysis of the chloramines and the formation of HOCl.

Effect of temperature. It has been generally found that the time required for a given chlorine concentration to kill 99% of the bacterial cells in a solution is reduced by about 50% for each 18°F (10°C) rise in temperature.

Temperature also affects the solubility of chlorine in water as shown in Table 2.12. This is not too important from the standpoint of in-plant chlorination, since even at 176°F, chlorine is theoretically soluble to the extent of 2,200 ppm. However, chlorine is rapidly reduced to an ineffective level as the temperature approaches the boiling point.

TABLE 2.12

SOLUBILITY OF CHLORINE IN WATER
AT DIFFERENT TEMPERATURES[1]

Temperature		Maximum % Chlorine Dissolved
°C	°F	
0	32	1.46
10	50	0.98
20	68	0.72
30	86	0.56
40	104	0.45
50	122	0.39
60	140	0.32
70	158	0.27
80	176	0.22
90	194	0.12
100	212	0.00

[1] Hodgman, 1947. Handbook of Chemistry and Physics.

Effect of organic matter. Small amounts of certain organic compounds in the water rapidly reduce the free residual chlorine, as shown in Table 2.13. The type of organic matter is an important factor. Dissolved sugars and starches apparently have little effect on the free chlorine residual, while proteins and other nitrogenous compounds definitely reduce it and thus decrease its germicidal effect. Filtering reused water in a pea cannery[1] to remove suspended matter only slightly reduced the chlorine demand of the water, indicating that in this case the soluble organic matter was responsible for the loss of free residual chlorine. Suspended matter may harbor bacterial cells from chlorine contact, thereby indirectly reducing the germicidal effectiveness of the solution.

2.224 CONTROLLED APPLICATION OF CHLORINE

When used in a food plant, chlorine must be applied under controlled conditions if the desired germicidal effects are to be obtained without adverse results. The discussion in this section is offered as a guide for implementation of chlorination programs in food processing plants.

2.2241 Survey of Water to be Chlorinated

To use chlorine effectively and efficiently, the chemical and physical nature of the water must be known. The following facts should be obtained: the average pH of the water, the temperature range, the chlorine demand, the concentration of organic matter, the volume to be chlorinated, and the presence in the water of phenols or other materials which might lead to off-flavors.

TABLE 2.13

EFFECT OF ORGANIC MATTER ON CONCENTRATION
OF FREE CHLORINE RESIDUAL IN WATER

Time in Minutes After Chlorine Added	Concentration of Free Chlorine		
	No Organic Matter	0.5 ml Tomato Juice per Liter of Water	1.0 ml Tomato Juice per Liter of Water
1.0	5.00	4.20	3.45
3.0	4.95	3.70	2.65
6.0	4.95	3.45	1.95
9.0	4.92	3.20	1.60
12.0	4.90	3.00	1.50

Chlorination should be considered for all raw water supplies not otherwise treated, with supplemental chlorination for water used in product washing, rinsing, conveyor lubricating, empty can washing, can cooling and general plant cleanup.

2.2242 Selection of the Chlorine Compound to Use

Selection of a suitable chlorine compound will depend to a great extent on the volume of water to be chlorinated, the desired chlorine residual level, and especially the use that will be made of the chlorinated water.

Chlorine gas. Chlorine gas is generally considered the best source for in-plant chlorination where large volumes of water are to be chlorinated to relatively high levels (4-5 ppm) because:

1. It is a pure substance, and no other materials are added.
2. It lowers the pH slightly.
3. It is easy to control and apply.
4. It is the cheapest source on the basis of pounds of available chlorine.
5. It is available only in cylinders which can be readily stored for extended periods without loss of the chlorine.

Chlorine gas requires the use of special metering equipment. A wide range of equipment, from simple metering devices to more elaborate measuring and controlling devices, is available.

Hypochlorites. Hypochlorites are a good source when only small amounts of chlorine are needed, such as in can cooling systems, in a localized germicidal application for cleanup purposes and for preventing slime formation on belts and other equipment. Hypochlorites require no special equipment and are, thus, simple to use.

Hypochlorites have several disadvantages which may limit their use under certain situations:

1. When they are added to water, other chemicals such as $CaCl_2$ and NaCl are produced which may have an adverse effect on the quality of the product.
2. The level of chlorine residual is difficult to control.
3. They raise the pH of the water; in hard water this may contribute to the formation of mineral deposits on equipment and cans.
4. They are more sensitive to organic matter in the water and thus lose their germicidal effectiveness more readily than chlorine.

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[1] Mercer, W. A., "Chlorination Studies on Reused Water in Pea Canneries," Paper, Annual Meeting, Northern California Section, Inst. Food Technologists (1951).

5. Being unstable they are difficult to store and deterioration results on long standing, especially with calcium hypochlorite.
6. Salts of heavy metals, even in small amounts, catalyze the disintegration of hypochlorites.
7. Their cost is high in terms of available chlorine content.

Chloramines. Chloramines are not suited for in-plant chlorination due to their slow action. However, because of their stability they are well suited for use when a long contact time is needed. For example, they may be used in wood holding tanks held full of water during the off season.

Chlorine dioxide. Chlorine dioxide has been found to be an effective germicide when considerable organic matter is present, such as in water which is reused. It does not react with ammonia or form chlorophenols which are responsible for offensive flavors frequently associated with chlorinated water. Because of its stability, chlorine dioxide is considered by some workers to be more effective than chlorine in treating cannery water for low bacterial residuals.

Special equipment is required to generate chlorine dioxide at the point of application. Although several types of generators are available, chlorine dioxide is most frequently produced by mixing an acidified chlorine solution with a sodium chlorite solution in a reaction chamber.

2.2243 In-plant Chlorination

In-plant chlorination provides a continuous application of germicidal chlorine to food preparation equipment, with the result that bacterial counts are reduced, slime formation is prevented, odors are avoided, and the time required to accomplish a satisfactory cleanup is shortened. The use of chlorinated water in can coolers will help to prevent spoilage due to recontamination.

Recommended chlorine levels. Free chlorine residuals of 4-7 ppm at the point of water application to equipment are recommended. If the operations are light, with only one shift, satisfactory control may be maintained by the lower concentrations, whereas during heavy or continuous operation higher concentrations may be required.

An increase to chlorine residuals of 10-20 ppm is recommended for cleanup purposes. This serves to give an effective germicidal treatment to all equipment in the plant.

Effect on food quality. The effects of chlorine on the flavor of fruits and vegetables have been studied.[1] The results are summarized in Table 2.14. Of the products tested it is evident

TABLE 2.14

EFFECT OF CHLORINE TREAMENT ON FLAVOR OF CANNED FOODS

PRODUCT	Lowest concentration which produced off-flavor when 2, 5, 10 and 50 ppm of chlorine were added. Partial treatment. Chlorination of all water except brines & syrups	Complete treatment. Chlorination of all water including brines & syrups
	Chlorine, ppm	Chlorine, ppm
Applesauce, Rome Beauty*	10	5
Applesauce, Gravenstein*	(None at 50)	10
Apricots, halves unpeeled	(None at 50)	50
Apricots, whole peeled	(None at 50)	50
Asparagus, all green	50	50
Beans, green cut	50	10
Beans, green limas	50	10
Beans, with pork (recanned)*	–	50
Beets, red sliced	50	10
Carrots, sliced	(None at 50)	10
Carrots, pureed*	(None at 50)	50
Cherries, Royal Anne	(None at 50)	50
Corn	–	(None with 15)
Figs, whole Kadota	50	5
Grapefruit juice (recanned)*	–	50
Orange juice (recanned)*	–	50
Peaches, clingstone halves	(None at 50)	5
Peaches, Elberta halves	(None at 50)	10
Peas	–	(None with 15)
Pears	50	2 to 5
Pineapple juice (recanned)*	–	10
Potatoes, sweet, solid pack*	(None at 50)	50
Pumpkin, solid pack*	(None at 50)	50
Prunes, Italian	(None at 50)	10
Spinach	50	10
Strawberries, whole	(None at 50)	5 to 10
Tomato juice*	–	10
Vegetable juice cocktail (recanned)*	–	5
Yams, syrup pack	–	5

*Chlorine added directly to the product.

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[1] Somers, I. I., "Studies on In-Plant Chlorination, "Food Technol., *5*(2):46-51 (1951).

that apples, pears, cling peaches, figs, strawberries and yams are the most susceptible to chlorine flavor. However, when unchlorinated water was used for syrups and brines, off-flavors did not develop when chlorine concentrations recommended for in-plant chlorination were used. Tests on these products showed that a chlorine concentration of 5 ppm has no effect on color or ascorbic acid content.

Effect on cans and equipment. Chlorine is corrosive to common metals as shown in Table 2.15. However, at low concentrations such as are used for in-plant chlorination (2-5 ppm), it does not noticeably corrode either cans or equipment under ordinary conditions. This conclusion is based on years of experience by many canners using in-plant chlorination. Some packers have reported that less corrosion takes place when chlorine is used; corrosion is most severe under slime deposits and chlorine effectively prevents slime formation. Even the high concentrations (10-20 ppm) used for cleanup do not generally produce significant corrosion because the contact time is short. However, while corrosion attributable to chlorination is not normally a problem, its possibility should not be completely ignored. If can cooling water contains sulfates or chlorides, the addition of chlorine increases the tendency toward can corrosion; the addition of a corrosion inhibitor such as sodium chromate may be necessary.

Equipment for in-plant chlorination. Two types of gas chlorinators are commercially available. One mixes the chlorine gas with a stream of water and injects the resultant solution back into the supply line. The other type meters chlorine gas directly into the supply line. Examples of both types are illustrated in Figures 2.16 and 2.17.

TABLE 2.15

EFFECT OF CHLORINE ON METAL AND OTHER SURFACES

Material	Effect of Chlorine Solutions		
	5 ppm	100 ppm	1,000 ppm
Glass, earthenware, silver[1], tantalum, most precious metals, bitumastics (tar), hard rubber	None	None	None
Soft gum rubber, fabrics, concrete	None	None	Disintegrates
Wood	None	None	– – –
Iron, steel, stainless steel, copper, brass, aluminum, tin	None	Corrodes[2]	Corrodes

1. Protection of silver is due to formation of silver chloride and if this is removed by abrasion corrosion will result.
2. Corrosion occurs if application is continuous. A periodic application of a few minutes contact may have very little effect. The lower the pH the more corrosion will result.

"Homemade" gas chlorinators are not advisable where accurate control is necessary. Cylinders of chlorine should preferably stand on platform scales while being discharged. This provides a means for measuring the rate of discharge and indicates when the cylinders are empty.

Hypochlorites are added by pumping or aspirating a solution into the waterline. Pump hypochlorinators can be used for chlorinating either closed or open water systems; in closed systems the solution is pumped directly into the line. These pump chlorinators are made of noncorroding material and may

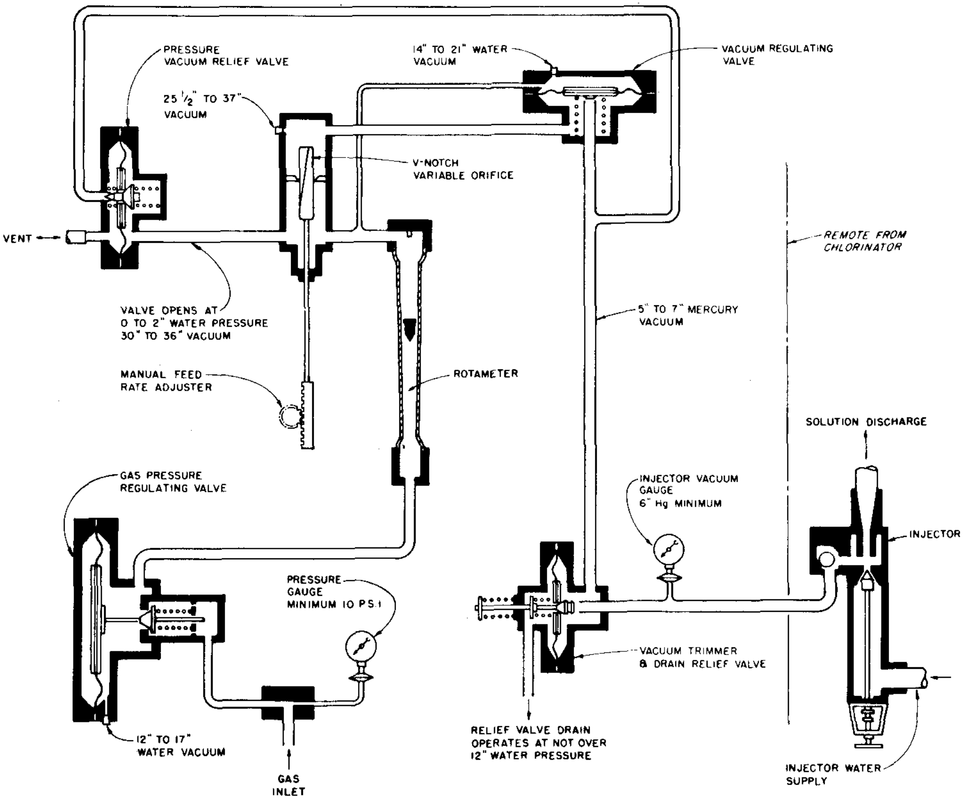

Figure 2.16. Flow diagram of a high-rate chlorinator with manual control. (Courtesy Wallace & Tiernan, Inc.)

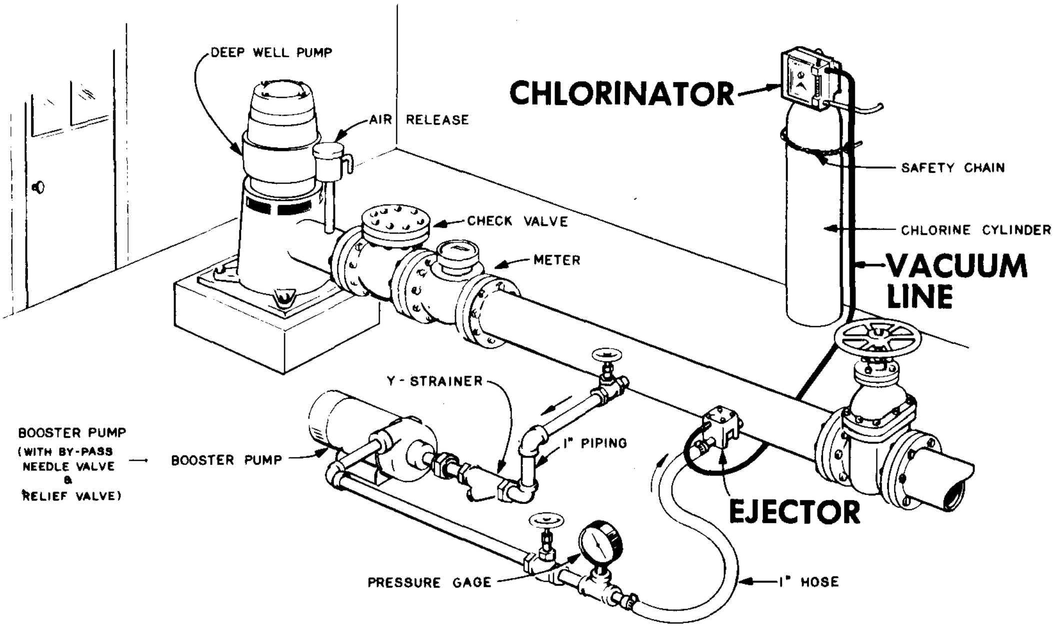

Figure 2.17. Equipment for direct injection of gaseous chlorine into water supply lines. (Courtesy of Capitol Controls)

be equipped to add hypochlorite solution in proportion to the water flow. A simple method for chlorinating well water is to connect the solution feed pump to the pump motor in such a way that the chlorinator operates whenever the well pump is operating. Aspirator type hypochlorinators are also available; these add the solution in proportion to the flow of water through a pressure line.

Regardless of the source of chlorine, only automatic equipment which feeds the chlorine in proportion to the water flow should be used. This is necessary to avoid fluctuations in the chlorine level which would be ineffective if too low or might produce off-flavors and corrosion if too high.

For in-plant chlorination to be most effective there should be a continuous application of chlorinated water to all surfaces where bacteria are likely to grow and slime is likely to form. This may involve additional piping. For belts, bucket elevators, reel washers and similar equipment, the chlorine may be applied by installing sprays of chlorinated water in such a way that will constantly bathe the moving surfaces. Best results are obtained on belts when the chlorinated water is sprayed on both surfaces of the belt.

For cannery equipment (such as fillers, dicers, peelers, etc.) where a continuous application of chlorinated water is not possible, waterlines should be installed near each machine. Short hoses can then be used for washing the equipment each time operations cease.

As a precaution against off-flavors and to avoid any employee objection, it is advisable to install lines of unchlorinated potable water for syrup or brine making and for drinking purposes.

Precautions with in-plant chlorination. Following the installation of chlorination equipment, all lines in the water system should be purged for at least a week prior to commencement of canning operations. Any organic matter which may be present in the lines will be oxidized by the chlorine, thereby eliminating subsequent off-flavor problems.

If there has been no previous experience with the use of chlorinated water on the products being processed, an experimental pack using chlorinated water should be made prior to the start of operations. To determine the possibilities of off-flavor development, chlorine may be added directly to the canned product in the approximate concentrations of 2, 5, 10 and 25 ppm; the level at which any flavor change occurs should be recorded.

All cresols, phenols or phenol-like compounds should be removed from the processing areas since chlorine in combination with such materials produces compounds which have very strong flavors even when present in minute quantities. Materials which may contain phenols and cresols are marking inks, paints, fly sprays, special wood sealers, hand lotions and boiler feedwater compounds.

Every precaution must be exercised to avoid personal contact with chlorine gas. Exposure to even low concentration can cause skin irritation and serious injury to the lungs and throat, while exposure to high concentrations will be fatal. Chlorine cylinders should be handled carefully, never dropped or rolled, and should be stored in an upright position in a well ventilated area readily accessible for inspection.

A chlorinator installation should be located in a room above ground with good ventilation. Should leaks occur in the system, chlorine gas, being heavier than air, will accumulate in a basement room and toxic concentrations may develop. State and local regulations must always be met. Since liquid chlorine expands very rapidly when heated, the cylinders are equipped with fusible plugs which melt at about 158°F and release the gas as a precaution against explosion. It is desirable, therefore, to have the chlorinator room and the chlorine storage area of fireproof construction and to keep the cylinders away from heat. In case of fire, chlorine cylinders should be removed from the building; if this is not possible, firemen must be informed of the storage locations.

If a leak occurs in a chlorine cylinder, steps should be taken to correct the condition immediately since chlorine leaks always become worse. Never spray leaking cylinders with water since chlorine reacts with water to produce heat, thereby increasing the pressure in the cylinder and augmenting the escape of chlorine. Gas evolution from chlorine spilled on the floor or ground can be reduced by spraying with cold water. Keep to the windward side and higher than the leak. If a chlorine container is leaking and is in a position that would cause liquid chlorine to escape, it should be inverted so that only gas escapes. The quantity of chlorine escaping from a gas leak is about one-fifteenth the amount that escapes from a liquid leak through the same size hole. If a leak occurs in chlorination equipment, close the cylinder valve immediately.

A bottle of ammonia should be kept in the chlorinator room for use in checking for gas leaks. The open bottle of ammonia, or a rag wrapped on a stick and soaked in ammonia can serve as a simple leak detector when located near chlorine equipment. If chlorine is present, a white cloud will appear. A chlorine gas mask (U.S. Bureau of Mines approved; the common industrial type is not satisfactory) should be provided for each employee who might be exposed to chlorine.

Chlorine may be absorbed in caustic soda, soda ash or hydrated lime solutions. Caustic soda is recommended. The amounts of alkali recommended for this purpose by the Chlorine Institute are given in Table 2.16.

One man should be responsible for the repair, care and maintenance of chlorination equipment. Whenever a leak is suspected or malfunctions occur, he should be called and everyone else should leave the area. It is desirable to hang a chart of instructions in areas where chlorine is used to inform employees of procedures to be followed in the event of an accident. These charts may be obtained from chlorine manufacturers.

Control of in-plant chlorination. In addition to proper installation, operation and maintenance, continuous laboratory control is essential for safe application of in-plant chlorination. The following control schedule is recommended:

1. Check the chlorine residual every 2 hours for the first week using the orthotolidine flash test (see Section 2.2261). This will help to establish what variations are likely to be encountered.
2. After the first week check the chlorine residual at several points in the plant at least twice a day. Always sample at the same places each day. If possible, take the sample from a tap that has been running for several minutes. A sample taken from a tank, flume, etc., may not give true values.
3. Keep a record of all residuals observed.
4. Taste the water (if it is potable) every time a residual is taken, as a check for possible off-flavors.
5. Record the chlorinator setting each time the residual is taken. After a few days it may be possible to correlate residuals with chlorinator settings; wide discrepancies would indicate that something is wrong. Also, the chlorine demand of the water may be estimated by calculating the theoretical residual, and subtracting from this the observed residual.
6. Weigh the chlorine cylinder each day at the same time, and record the loss in weight. This is a check on the accuracy of the chlorinator feed setting; weight records will indicate when a cylinder has been depleted.
7. Check the chlorinator operation, and at least once a day inspect for leaks using an ammonia bottle as described previously.
8. For hypochlorinators, check and record the volume of chlorine solution in the supply tank, and each day calculate the gallons of solution that have been fed per hour during the previous day.

TABLE 2.16
RECOMMENDED ALKALINE SOLUTIONS
FOR ABSORBING CHLORINE[1]

Chlorine Container Size-lb Net	Caustic Soda		Soda Ash		Hydrated Lime[2]	
	lb 100%	Water Gal.	lb	Water Gal.	lb	Water Gal.
100	125	40	300	100	125	125
150	188	60	450	150	188	185
One ton	2500	800	6000	2000	2500	2500

1. This table taken from chlorine manual published by the Chlorine Institute, Inc., 50 East 41st Street, New York, N.Y., p. 19.
2. A hydrated lime solution must be vigorously and continuously agitated while chlorine is being absorbed.

2.2244 Cooling Water Chlorination

When cooling water is reused or has a high bacterial content, chlorination is advisable. When cans are to be processed in retorts or continuous cookers, chlorination of cooling water should always be accompanied by can washing after filling and sealing to reduce the amount of organic matter which might be carried into the cooling system and increase the chlorine demand.

Cooling towers. Water that is cooled for reuse in can coolers by passage over a tower may be highly contaminated with microorganisms, and rechlorination is usually necessary. Sufficient chlorine should be added to the water as it leaves the tower so that a free residual of approximately 0.5 ppm exists in the water exiting the can cooler. This treatment should be accompanied by screening of the water to remove any large foreign objects. Additionally, means should be provided by which higher concentrations of chlorine (4-5 ppm) can be applied directly to the cooling tower, as illustrated in Figure 2.18. The tower should be treated for a few hours every week or two to eliminate growths of microorganisms which may gradually develop.

Tank, canal, and rotary continuous coolers. Bacterial counts may rapidly build up to high levels in tank, canal or continuous rotary coolers unless the water is chlorinated. A free chlorine residual of at least 0.5 ppm at the discharge end of the cooler is recommended. When in-plant chlorination is practiced, the 5 ppm residual carried in the cooler inlet water is often sufficient to maintain the necessary 0.5 ppm at the discharge end of the cooler without additional chlorination.

Application of chlorine compounds. Chlorination of cooling water may be accomplished with either gaseous chlorine or hypochlorites. Either automatic or manual feed equipment may be used, but it is sometimes more difficult to get accurate control with a manual feed. The same precautions apply for these installations as described under in-plant chlorination with gaseous chlorine.

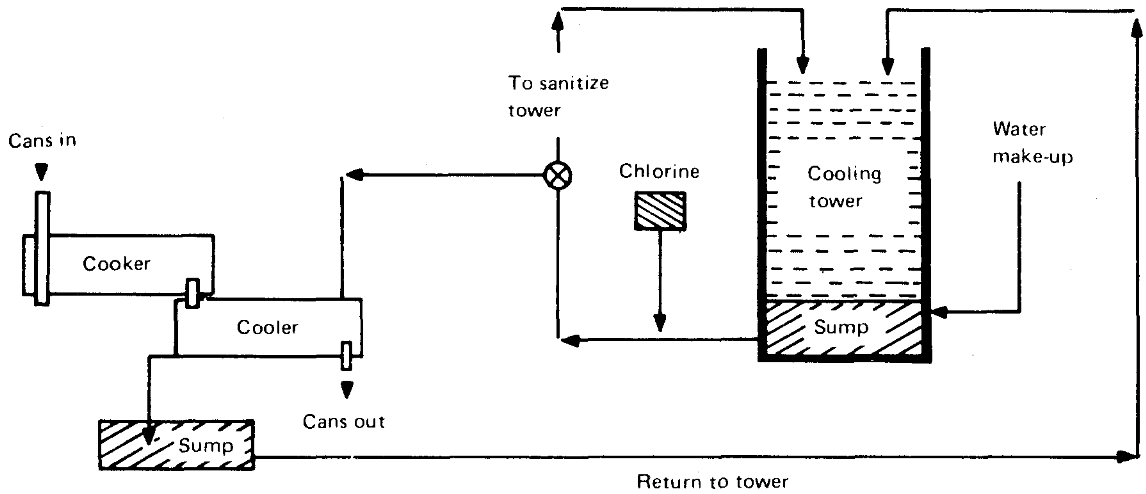

Figure 2.18. Chlorination of can cooling water recycled over a cooling tower.

For cooling canals and open coolers, hypochlorites are generally used; these may be metered into the system with a chemical solution feed pump, or, if no other means are available, by a drip feed mechanism. Drip feed equipment is satisfactory for applying sodium hypochlorite solutions. Calcium carbonate deposits which form from calcium hypochlorites may clog drip feed equipment, thereby impairing controllability. Calcium hypochlorite solutions should be mixed several hours before use to allow the carbonate deposits to settle; pumps are advisable for addition of calcium hypochlorite solutions.

Laboratory control. The following checking routine is recommended for cooling water chlorination:

1. Chlorine residuals and the operation of the chlorinator should be checked at least every 2 hours when chlorination is initiated, and at least every 4 hours after the first week.
2. The solution tank should be calibrated so that the gallons fed per hour can be calculated each time a check is made.

2.2245 Chlorination of Water Reused for Other Than Cooling

When reusing water in food preparation departments, the best and safest method is the counterflow principle with successive uses of the water in reverse order to the flow of product through the lines (see Section 2.122, Counterflow Water Reuse Systems). Fresh water is used for the final washing or fluming of the product prior to canning. The second or third uses may be for fluming or washing at intermediate stages in the preparation, and the last use for washing or pumping the raw product as it enters the preparation lines. The exact details of such a system must be worked out for each facility since no two plants handle a given product in exactly the same manner.

In a counterflow system water is collected in a separate tank after each use and should be rechlorinated at this point prior to reuse. Since the chlorine demand of the water will vary after each use, different amounts of chlorine must be added to each tank. One of two rechlorination systems may be used.

1. Small, cylinder-mounted chlorinators may be provided at each collection tank of the counterflow system. Each chlorinator may then be independently adjusted to provide the chlorine feed rate required to maintain the desired chlorine residual concentration. This system is also suitable for chlorination of water recirculation systems.
2. A single chlorinator, separate from the fresh water in-plant chlorinator, may be used to provide a concentrated chlorine solution for the counter-flow system. The chlorine gas may be injected into a header pipe to generate the concentrated solution which can then be distributed to the collection tanks. The chlorine solution should be supplied to each tank through individual adjustable valves, thereby providing control of feed rates and chlorine residuals within each tank. A period of experimentation will be necessary to determine the appropriate feed rates for each valve and for the chlorinator.

   All components of this arrangement must be constructed from chlorine-resistant materials which are available from chlorinator manufacturers. The concentrated chlorine solution supplied to each tank must be added below the water surface within the tank to prevent liberation of chlorine gas into the atmosphere around the equipment.

A minimum chlorine residual of 5 ppm should be maintained in fresh water added to a reuse system. However, the chlorine will combine with the organic matter present in the system, thereby necessitating rechlorination prior to reuse. Experience has shown that the most economical yet effective chlorine dosage for reused water is that which produces a free residual of 0.10 to 0.50 ppm when measured at the end of the subsequent use by the orthotolidine flash method. This assures complete satisfaction of the chlorine demand of the water and provides a fairly high total residual. Because of the extended period in which the water is used, the total residual exerts enough germicidal activity to prevent the multiplication of micororganisms.

2.225 CHLORINE DOSAGE CALCULATIONS

Calculating Gaseous Chlorine Dosage

The rate of chlorine application is generally measured in pounds per 24 hr, and chlorinators are calibrated on this basis. The dosage is checked by weighing the cylinders.

The amount (in pounds per 24 hr) of chlorine gas necessary to give a certain residual can be estimated as follows:

$$W = \frac{8.34\ DG}{1{,}000{,}000}$$

where

D = dosage in ppm desired
G = gallons of water per 24 hr to be chlorinated, and
W = weight of chlorine to be added in pounds per 24 hr

Example. To obtain a 4 ppm free chlorine residual in a line delivering 600,000 gal. per 24 hr, the rate of chlorine addition would be:

$$\frac{8.34 \times 4 \times 600{,}000}{1{,}000{,}000} = 20 \text{ lb per 24 hr}$$

These calculations assume a zero chlorine demand of the water. However, if the water contains considerable organic matter, it is desirable to determine the chlorine demand (see Section 2.2268) before starting to chlorinate, since a larger capacity chlorinator may be required.

Chlorine demand is measured in ppm and increases the dosage proportionately.

Using the example above, if the chlorine demand were 3 ppm, a dosage of 7 ppm would be required to obtain a free residual of 4 ppm. The calculation would be:

$$\frac{8.34 \times 7 \times 600{,}000}{1{,}000{,}000} = 35.0 \text{ lb of chlorine per 24 hr}$$

These calculations give the approximate setting for the chlorinator to obtain 4 ppm. However, actual residuals often vary from the theoretical due to variations in impurities of the water. The final setting should therefore be based on chlorine residual tests. The orthotolidine method is satisfactory for this purpose.

Calculating the Hypochlorite Dosage

Hypochlorite stock solutions are usually of 0.5% (5,000 ppm) concentration. However, if the volume of water flow is large, a 1% solution is recommended to reduce both the volume added and the size of the stock solution container. Thirty gallons per day is usually considered a good rate of feed.

Stock solution. The weight or volume of hypochlorite required in making up a stock solution may be calculated as follows:

For calcium hypochlorite powders: $H = \frac{8.34\ gP}{p}$

For sodium hypochlorite solutions: $V = \frac{gP}{p}$

where

H = pounds of hypochlorite powder required
V = gallons of hypochlorite solution required
g = gallons of stock solution desired
P = percent (decimal equivalent) chlorine desired in the stock solution
p = per cent (decimal equivalent) available chlorine in the hypochlorite

Example. Assuming 100 gal. of 0.5% solution is desired, calculate the amount of a 65% available chlorine hypochlorite powder to add to the 100 gal. of water as follows:

$$\frac{8.34 \times 100 \times 0.005}{0.65} = 6.41 \text{ lb}$$

Dosage calculation. The amount of stock solution to add to a given water supply (assuming zero chlorine demand) may be calculated as follows:

$$A = \frac{GD}{1{,}000{,}000\ P}$$

where

A = gallons of stock solution to be added
G = gallons of water to be chlorinated
D = dosage in ppm desired
P = per cent (decimal equivalent) chlorine in the stock solution

Example. Assume 50 gal. of water per minute are to be treated at the rate of 2 ppm with an 0.5% stock solution.

$$\frac{50 \times 2}{0.005 \times 1{,}000{,}000} = 0.02 \text{ gal. per minute (28.8 gal. per 24 hr)}$$

If the water has a chlorine demand, apply a correction for this demand as explained under calculation for gaseous chlorine dosage.

2.226 METHODS FOR MEASURING CHLORINE CONCENTRATIONS

The following tests can be used to routinely monitor chlorine levels in water systems and to determine the chlorine demand of raw waters. With the exception of the amperometric titration method, the procedures outlined below require only simple equipment and can be followed with relative ease.

2.2261 Orthotolidine Test for Chlorine Residuals

The orthotolidine method is widely used for checking chlorine residuals. The procedures described here have been adapted from *Standard Methods.*[1]

Reagents

Orthotolidine. To prepare this reagent, dissolve 1.35 gm of orthotolidine dihydrochloride in 500 ml of distilled water. Add this solution, with constant stirring, to 500 ml of dilute HCl which is made by mixing 350 ml of distilled water and 150 ml of concentrated HCl (sp. gr. 1.18-1.19). Store this solution in a dark, cool (but not cold) place or in amber bottles away from direct sunlight. Do not let it come in contact with rubber. The reagent will keep for about 6 months. Orthotolidine reagent may be purchased ready for use from chemical supply houses.

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1. "Standard Methods for the Examination of Water and Wastewater," 14th edition, Amer. Pub. Health Assn., Inc., New York, N.Y. (1976).

Equipment

Comparator. The chlorine test is made by adding orthotolidine solution to the water sample and matching the color produced with a standard color which represents a given chlorine residual. Two general types of comparators are available, one using color discs (Fig. 2.19) and the other standard solutions in a block (Fig. 2.20). Standard solutions are available from chemical supply houses or may be prepared as directed in Standard Methods.

Light source. The best light is an illuminated white surface, while second choice is good north light. Never use direct sunlight.

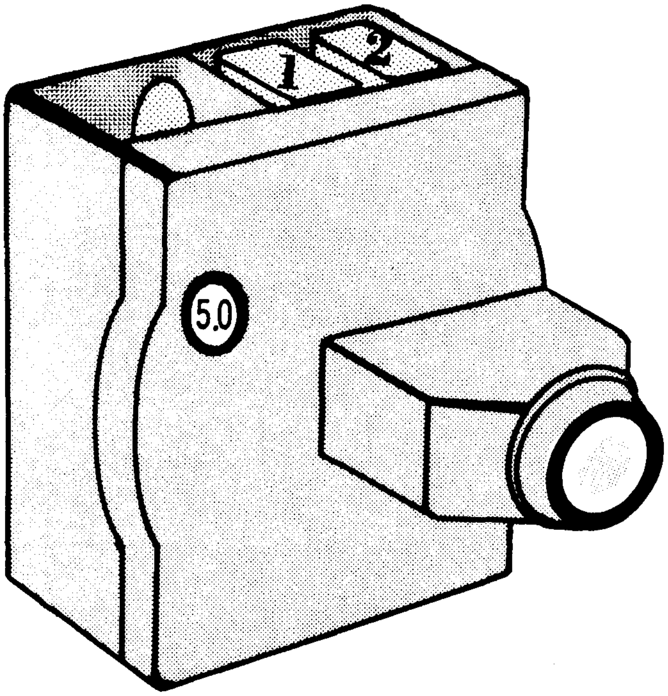

Figure 2.19. Disc comparator.

Procedure for disc comparator

1. Fill cell No. 2 to mark with the water to be tested and insert in the right cell space of the comparator. This will compensate for color and turbidity in the water sample.
2. Add 0.75 ml orthotolidine reagent to cell No. 1 by means of a dropper and fill to the mark with the water under test. Mix.
3. Insert the cell containing the water and orthotolidine reagent in the left cell space of the comparator.
4. Obtain a reading as soon as possible (about 5 sec after adding orthotolidine). This indicates the flash or free chlorine residual.
5. Let stand for 5 min and read again. This indicates the approximate total chlorine residual. When 85-100% of the full color (as shown by 5 min reading) develops instantaneously, the break-point has been passed. This test may be used for indicating attainment of the break-point.

Procedure for block comparator

1. Fill tubes A, E and C to the 10 ml level with the water to be tested.
2. Add 0.5 ml of orthotolidine solution to tube E. (If the water volume is more than 10 ml add more solution in proportion to volume.) Mix rapidly by striking against finger.
3. Place tube E in the comparator and match color.
4. Obtain readings as indicated in Steps 4 and 5, above.

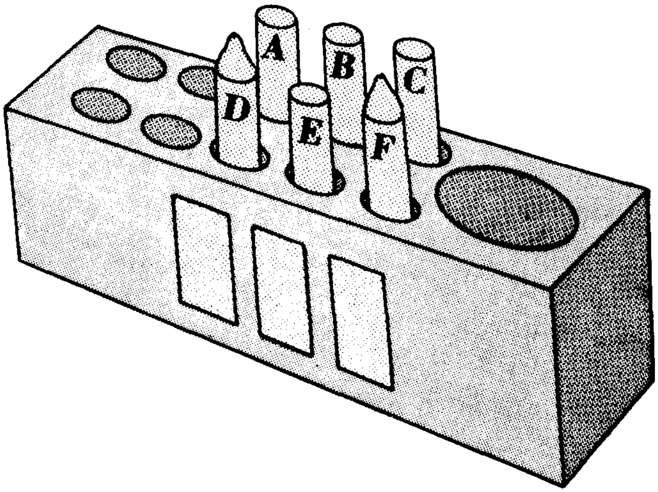

Figure 2.20. Block comparator. A, E and C are empty test tubes with a mark at the 10 ml level. B is a tube of distilled water. D and F are standard color tubes. These are changed to match colors.

Discussion of method. The maximum color is developed in 5 min, and fading may occur after this time. During color development the sample should be kept in the dark. If the sample is colder than 68°F, bring it to this temperature rapidly after adding orthotolidine. When testing water from a pipe, always take the sample from a tap that has been allowed to run for several minutes before sampling.

If the water contains suspended solids or coloring matter, the readings may be incorrect. Compensation for color and/or turbidity can generally be achieved by placing a tube or cell filled with the water being tested behind the color standard, as directed under Procedure. However, large amounts of suspended matter, when present, should be removed by centrifuging before the test is made.

Nitrites, and ferric and manganic substances tend to increase the apparent chlorine residual. If the amount of these materials is too high, the orthotolidine-arsenite method should be used. These interfering substances are most likely to be of significance in water from deep wells that is chlorinated to a marginal level of 0.2-0.4 ppm but are generally not significant in water that is chlorinated beyond the break-point. The iron content of reused cooling water may increase, but the iron is usually precipitated by chlorine to an extent that it does not interfere with residual tests.

The orthotolidine method is quite accurate for chlorine residuals below 1 ppm but is more of an approximation above this level. However, residuals can be determined by this method up to 10 ppm with sufficient accuracy for most chlorination procedures. If more precise results are desired, the starch-iodide method should be used.

2.2262 Drop Dilution Method for Chlorine Residuals above 10 ppm

The Drop Dilution Method of residual chlorine determination consists of the addition of one or more drops of the water under test to a cell of known volume containing orthotolidine and distilled water.[1] This method has the advantage of simplicity, speed, and reasonable accuracy.

Materials and Equipment

1. Distilled water.
2. A dropper which will deliver a known number of drops per ml. The average dropper should deliver between 19 and 21 drops per ml.
3. A comparator, complete with 10 ml sample tubes (Fig. 2.20).
4. Orthotolidine solution.

Procedure

1. Collect sample in small glass container.
2. Add 0.5 ml of orthotolidine solution to tube B of the comparator and fill to 10 ml mark with distilled water. (Wallace and Tiernan sample cells contain 15 ml when filled to mark and the droppers contain 0.75 ml when filled to mark.)
3. Fill the other tubes with distilled water.
4. Add one drop of water under test to tube B, mix and read immediately. If no color appears, add additional drops, one at a time, until a reading within the range of the color standard is obtained.

Calculation. Compute the residual as follows:

$$\frac{\text{capacity of cell}}{\text{ml of chlorinated water}} \times (\text{comparator reading}) = \text{ppm chlorine present}$$

Example. Suppose one drop of the sample (chlorinated water) added to the center tube shows a residual of 0.20 ppm.

Capacity of cell = 10 ml
ml sample added = 0.05 (1 drop)
Comparator reading = 0.20

Substituting these values, 10/0.05 X 0.20 = 40 ppm residual

2.2263 Orthotolidine - Arsenite Test for False Chlorine Residuals

This test was developed to determine the amount of interfering substances, usually manganese, iron and nitrites, that develop the characteristic yellow color with acid orthotolidine which gives rise to false chlorine residuals.[2] Through the use of an arsenite solution in conjunction with the acid orthotolidine, the value of this false residual is measured in terms of ppm chlorine.

Reagents

1. Arsenite solution. 5 gm of sodium arsenite dissolved in 1 liter of distilled water.
2. Orthotolidine solution. The same reagent as used in the regular acid orthotolidine test for determining chlorine residuals.

Procedure

1. Add 0.5 ml arsenite solution to 10 ml test sample and mix thoroughly.
2. Add 0.50 ml acid orthotolidine solution to the test sample and mix thoroughly.
3. Observe the reading immediately if interested in the free chlorine residual or read in 5 min if interested in the 5 min chlorine residual. These readings give the false chlorine residuals and when subtracted from the acid orthotolidine chlorine residuals, the actual chlorine residuals are obtained.

2.2264 Starch-Iodide Test

The Starch-Iodide (or Iodometric) Method is most accurate for determining total available residual chlorine. Under acid conditions chlorine will liberate free iodine from potassium iodide solutions. The liberated iodine is titrated with a standard solution of sodium thiosulfate, using starch as an indicator.

Reagents

1. KI (potassium iodide) crystals, U.S.P.
2. Glacial acetic acid.
3. 1% water soluble starch solution. Boil 10 min and decant after standing overnight.
4. 0.01 N sodium thiosulfate solution. Prepare an 0.1 N stock solution of sodium thiosulfate as described in Section 3.512. Prepare the 0.01 N titrant solution by diluting 100 ml of the stock solution to 1.0 liter with freshly boiled and cooled distilled water. Standardize the titrant solution as described in Section 3.522.

Procedure

1. Place a few crystals of KI in a wide mouthed erlenmeyer flask.
2. Add approximately 10 ml of distilled water.
3. Add 2 ml of glacial acetic acid.
4. By means of a volumetric pipette, add 100 ml of the chlorinated water being tested. The tip of the pipette should almost touch the surface of the water to avoid surface loss.
5. Titrate with 0.01 N sodium thiosulfate solution using starch as an indicator near the end point of the titration.
6. Read the burette at the first disappearance of color; disregard reappearance of color upon standing.

Calculation. Calculate the total available residual chlorine concentration as follows:

$$\text{ppm } Cl_2 = \frac{\text{ml thiosulfate X normality X } 35{,}450}{\text{ml sample}}$$

2.2265 Amperometric Titration Method

Amperometric titration for the determination of chlorine is an extremely accurate method for laboratory analysis. Total residual chlorine can be determined and free and combined available chlorine can be differentiated by this method. Free available chlorine is determined by titration with phenylarsine oxide solution at a pH between 6.0 and 7.5, a range in which the combined chlorine does not react. The combined chlorine, in turn, is titrated in the presence of the proper amount of potassium iodide in the pH range 3.5 to 4.5 The endpoint of the titration is detected by a special galvanic cell consisting of a nonpolarizable reference electrode and a readily polarizable noble-metal electrode, both connected to a microammeter. When no chlorine residual is present in the

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[1] Griffin, A. E., "The Break Point Process," Technical Publication 213, Wallace & Tiernan Company (1944).

[2] Hallinan, F. J., "Tests for Active Residual Chlorine and Chloramines in Water," J. American Water Works Assoc., *36*:296(1944).

sample, the meter reading will be low due to cell polarization. As the residual in the sample increases, the cell is more effectively depolarized, resulting in increased meter readings. As phenylarsine oxide is added gradually, the cell becomes increasingly polarized due to the decrease in available chlorine. The endpoint is recognized when no further decrease in meter reading can be obtained by subsequent additions of phenylarsine oxide.

Reagents. The following reagent solutions can also be obtained from manufacturers of amperometric titrators.

1. Standard phenylarsine oxide titrant. Dissolve 0.8 gm phenylarsine oxide powder, C_6H_5AsO, in 150 ml 0.3 N NaOH. Allow to settle. Decant 110 ml of this solution into 800 ml distilled water and mix thoroughly. Adjust to pH 6-7 with dilute HCl and finally dilute to one liter. Standardize to 0.00564 N against standard 0.0282 N iodine solution, using the amperometric titrator for the normality determinations: 1.00 ml equals 0.200 mg available chlorine. Preserve with 1 ml chloroform (Caution: toxic, avoid ingestion).
2. Phosphate buffer solution, pH 7. Dissolve 25.4 gm anhydrous potassium dihydrogen phosphate, KH_2PO_4, and 34.1 gm anhydrous disodium hydrogen phosphate, Na_2HPO_4, in 800 ml distilled water. Add 2 ml sodium hypochlorite solution containing 1% available chlorine and mix thoroughly. Protect from sunlight for several days and then expose to sunlight until no residual chlorine remains. If necessary, carry out final dechlorination using a sodium sulfite solution until only a trace of chlorine is evident in the orthotolidine flash test. Dilute to one liter with distilled water and filter if any precipitate is present.
3. Acetate buffer solution, pH 4. Add 480 gm (457.6 ml) glacial acetic acid and 243 gm sodium acetate trihydrate, $Na\ C_2H_3O_2 \cdot 3H_2O$, to 400 ml distilled water and dilute to 1 liter.
4. Potassium iodide solution. Dissolve 50 gm KI and dilute to 1 liter using freshly boiled and cooled distilled water. Store in brown glass-stoppered bottle, preferably in the refrigerator. Discard this solution when a yellow color develops.
5. The following reagents are required for standardizing the phenylarsine oxide titrant if this solution is prepared in the laboratory:

   a. Standard sodium arsenite, 0.1 N. Weigh a stoppered weighing bottle containing approximately 4.95 gm arsenic trioxide, As_2O_3, primary standard grade. Transfer to a one-liter volumetric flask and again weigh the bottle to obtain weight of As_2O_3. Disregard the oxide adhering to the bottle. Moisten the As_2O_3 with distilled water, and add 15 gm NaOH and 100 ml distilled water. Swirl the flask gently to dissolve the oxide. Dilute to 250 ml and saturate the solution with CO_2 to convert all the NaOH to sodium bicarbonate. Dilute to one liter and mix thoroughly. (Caution: toxic, avoid ingestion.)

   $$\text{Normality} = \frac{\text{gm } As_2O_3}{49.455}$$

   b. Standard iodine, 0.1 N. Dissolve 40 gm KI in 25 ml distilled water and then add 13 gm resublimed iodine and stir until dissolved. Transfer to a 1-liter volumetric flask and dilute to the mark. Standardize by accurately measuring 40-50 ml of 0.1 N $NaAsO_2$ solution into a flask and titrating with 0.1 N iodine solution using starch solution as indicator. To insure accurate results, add a few drops of hydrochloric acid just before the endpoint is reached. This will liberate sufficient CO_2 to saturate the solution.

   c. Dilute standard iodine, 0.282 N. Dissolve 25 gm KI with a small volume of distilled water in a 1-liter volumetric flask; add the proper amount of 0.1 N iodine solution exactly standardized to yield a 0.0282 N solution; dilute to 1-liter. Standardize this solution daily as directed above, using 5-10 ml of 0.1 N $NaAsO_2$ solution.

   Store the solution in an amber bottle or in the dark, protecting it from direct sunlight at all times. Avoid any contact with rubber.

Procedure

1. Sample volume. If the residual chlorine concentration in the sample is 2 ppm or less, use 200 ml for titration. For higher residual chlorine concentrations use a 100 ml sample. Samples requiring not more than 2 ml phenylarsine oxide solution yield best results.
2. Titration of free available chlorine. Unless the pH of the sample is between 6.0 and 7.5, add 1 ml pH 7 phosphate buffer solution. Titrate with phenylarsine oxide solution, observing current changes on the microammeter. Changes in meter reading after each incremental addition of titrant indicate presence of free available chlorine. As the endpoint is approached, the meter response to each increment will become more sluggish and smaller increments should be added. The endpoint is just passed when a very small increment of phenylarsine oxide no longer causes a decrease in current. This final increment should be subtracted from the burette reading to obtain the free available chlorine concentration.
3. Titration of combined available chlorine. To the sample from the free-chlorine titration add exactly one ml potassium iodide solution, followed by one ml acetate buffer solution. Titrate with phenylarsine oxide solution in the above manner. Subtract the final increment as previously done. Record the volume of titrant required, including that volume required for the free available chlorine determination. This represents the total residual chlorine in the sample. Subtracting the free available chlorine from the total gives the combined residual chlorine. If desired, these determinations can be made separately.

Calculation

$$\text{ppm Cl} = \frac{\text{A X } 200}{\text{ml sample}}$$

where A = ml titrant for sample.

2.2266 Standardization of Chlorine Water

Reagents

1. KI crystals, U.S.P.
2. Glacial acetic acid.
3. 1% water soluble starch solution. Boil 10 min and decant after standing overnight.

4. 0.1N sodium thiosulfate.
   (24.82 gm $Na_2S_2O_3 \cdot 5H_2O$ per liter). See Section 3.512.

Procedure

1. Place a few crystals of KI in a wide mouthed erlenmeyer flask.
2. Add approximately 10 ml distilled water.
3. Add about 2 ml glacial acetic acid.
4. By means of a volumetric pipette, add 10-50 ml Cl water to be tested. Tip of pipette should almost touch surface of water in order to avoid surface loss.
5. Titrate with 0.1 N sodium thiosulfate, using starch as an indicator near the end of the titration.
6. Read at first disappearance of color; disregard reappearance of color upon standing.
7. Calculate the chlorine in ppm as follows:

$$\text{ppm } Cl_2 = \frac{\text{ml thiosulfate} \times \text{normality} \times 35{,}450}{\text{ml of sample}}$$

2.2267 Determination of the Chlorine Break-Point of Water

To obtain a persistent residual chlorine level in water, the organic matter present in the water must first be oxidized. The quality of chlorine required to reach the break-point, as described in Section 2.222, can be determined by the following procedure.

Reagents.

1. Chlorine water—from chlorine gas, not hypochlorites. This may be obtained by bubbling chlorine through water. A fresh solution should be made frequently, preferably each day, and should be stored in an amber bottle. Standardize the solution just prior to starting the test. The solution should be made strong enough that the volume of the treated sample will not be increased by more than 5%. Suggested strengths for treating 500 ml portions are as follows:

For doses of:	Use chlorine stock solution of:
0-5 ppm	50-100 ppm
6-10 ppm	100-250 ppm
11-20 ppm	250-500 ppm

2. Orthotolidine indicator with comparator block.
3. 0.01 N sodium thiosulfate solution. See Section 2.2264.

Procedure

1. Prepare a series of 500 ml samples of the water to be tested. Maintain these samples at the temperature of the water in the treatment plant or supply line.
2. To each sample add an aliquot of the standard chlorine solution. Vary the sizes of the aliquots so that a wide range of chlorine dosage is covered. Stir constantly while chlorine is being added.
3. Allow these samples to stand for 30 min and then test for chlorine. Use the orthotolidine method for residuals up to 1 ppm and the starch-iodide titration for higher concentrations. When testing with orthotolidine take both 5 sec and 5 min readings. A 30 min contact time is suggested as an average value; however, it may be necessary to make tests with a number of contact times to determine the stability of chlorine as related to time.
4. Plot the chlorine dosage against the chlorine residuals observed. If the water has a break-point, it will be obvious as the point on the curve where the residuals start increasing for a second time almost proportionately to the dosage—see Fig. 2.15.

2.2268 Determination of the Chlorine Demand of Water

The chlorine demand of water can be measured by the method described above for the determination of break-point.

Chlorine demand = ppm of chlorine added minus
ppm of chlorine residual observed

The chlorine demand is always related to the dosage, contact time and temperature.

2.23 pH Control of Recirculated Water

The use of hydraulic conveying systems by food processors is expectedly extensive in view of the advantages which such systems offer – water is a convenient and efficient transport medium, hydraulic systems are generally more compact than dry conveyors, little attention is required for operation of hydraulic systems, maintenance of product appearance is enhanced by the gentler handling imparted by water, to name a few. To maintain acceptable aesthetic and sanitary conditions within hydraulic conveying systems, a large volume of water is generally added continuously, thereby resulting in a continuous overflow from the system. By dilution in this manner food particles and product juices which are washed or leached from the conveyed commodity are maintained at low concentrations within the system; microbial populations are likewise minimized. Where hydraulic conveying systems are used, the organic matter which is continuously discharged from each system is a major source of the total organic load associated with the processing operations. The water discharged from each system is a major contributor to the total hydraulic load of the plant effluent. Measures to reduce the waste loads from hydraulic conveying systems must include consideration of the sanitary condition of the water within the systems.

It is well established that the pH of water affects the growth rate of microorganisms. The optimum pH for most bacteria is the neutral range (pH 6.5 to 7.5). As the pH of the medium is made more acid or more basic, microbial growth rates decline. Under very acid or very basic conditions, bacteriostatic effects are evidenced. The growth responses observed in a simulated flume system are graphically illustrated in Figure 2.21 (989). These results are the basis for the use of pH control to maintain the sanitary condition of recirculated water. This control methodology is especially well suited for systems conveying naturally-acid products, such as tree fruits and tomatoes, and may be used for potatoes and other vegetables.

2.231 EXPERIMENTAL RESULTS

A demonstration project was conducted to confirm on a commercial scale the findings of the earlier laboratory study. Two identical pumping systems were used for this investigation. In each of these systems cling peach halves were dis-

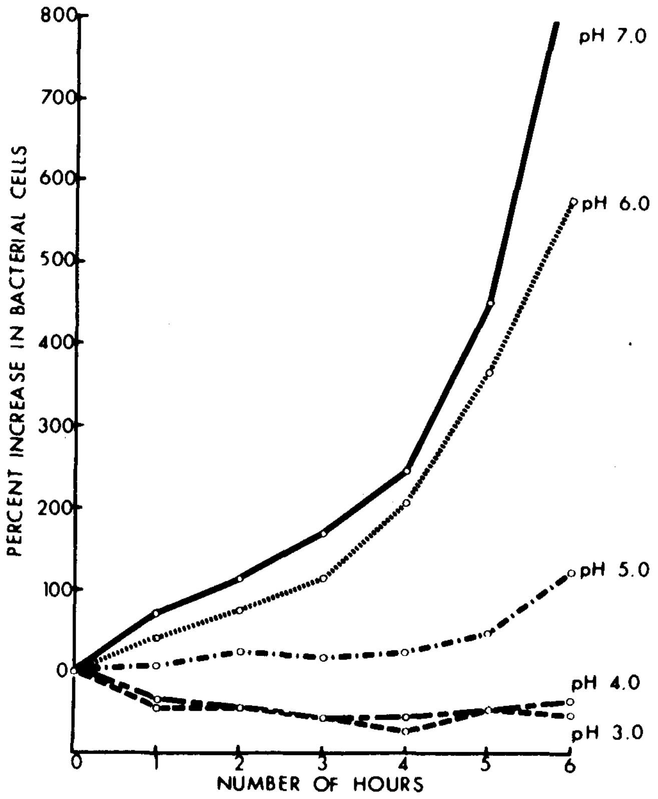

Figure 2.21. Effect of pH control on the growth of bacterial cells.

charged into tanks and pumped to the filling operation. The peaches were dewatered and delivered to can fillers; the water was returned to surge tanks for recycling. Fresh water could be added to each system as required. In one system pH control capabilities were provided, as graphically depicted in Figure 2.22. Citric acid, an edible acid which naturally occurs in fruits and tomatoes, was used to acidify and maintain the water at pH 4.0. The parameters monitored for each system included the volume of water consumed, bacterial counts on representative samples, temperature, pH and BOD; the quantity of acid used in the test system was measured.

The amount of fresh water added to each system and the quantity of BOD generated by each are summarized in Table 2.17. In this case, the acidified pumping system used only 25 percent as much fresh water and generated only 70 percent as much BOD as did the unacidified control system.

Results of tests performed on samples collected from the two systems are summarized in Table 2.18. The relative bacterial count was obtained by reducing the total plate count to a common denominator. Results are reported for samples taken at 2-hour intervals over a 24-hour period. Almost without exception, the bacterial count in the acidified system was equal to or lower than the count in the control system.

The quantity of citric acid required to maintain pH 4 within the system will be dictated by the rate of fresh water addition, as well as the pH and buffering capacity of the raw water and the commodity being transported. Citric acid consumption in relation to the volume of water added to the system, averaged over several days of operation under the test conditions described above, are summarized in Table 2.19.

Use of the pH control system resulted in reduced consumption of water required to maintain sanitary conditions in the recirculated water system. The acidified system was operated at the make-up rate equal to 25 percent of the control system. The second principal benefit of using less water is the resultant reduction in the volume of effluent. Using the current water charges in one California community, the reduced intake of fresh water would pay for the citric acid used in controlling the pH of the water. A water savings of 20,000 gallons per day would reduce the water bill by $6.00. Using an average of 2.5 pounds of citric acid per hour and 10 cents per pound, the cost of the acid would be equal to the savings in the smaller volume of water used. There would be a net savings in sewer service charges for the reduction in the volume of effluent and pounds of BOD discharged.

The pH control system was operated continuously for only 24-hour periods. It is very possible that even longer periods of operation could be used and the consumption of fresh water further reduced. This would result in even greater savings in water, citric acid and fewer pounds of BOD discharged.

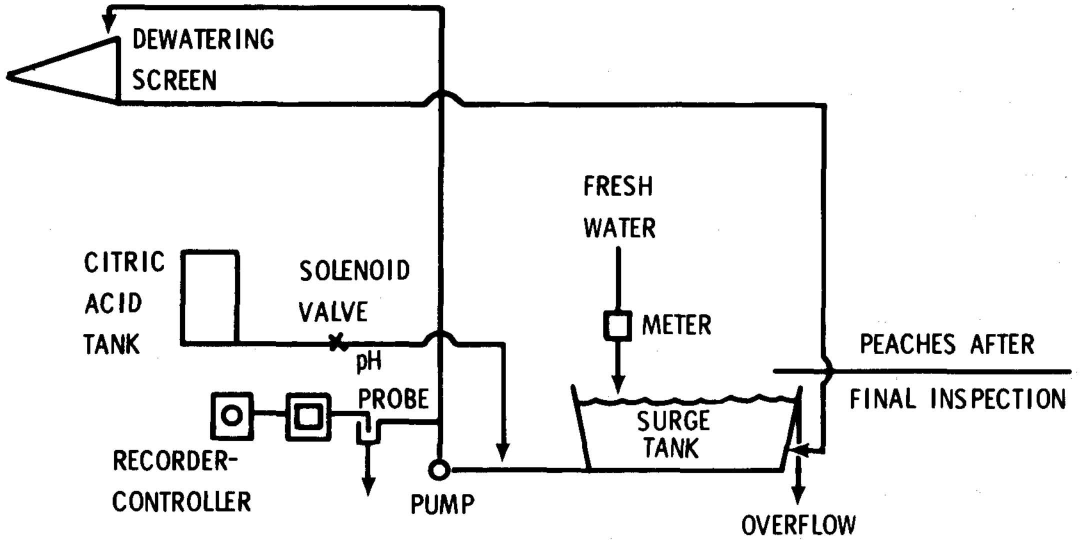

Figure 2.22. pH control system.

TABLE 2.17

CHARACTERISTICS OF FRUIT PUMPING WATER

(24 hours of operation)

Measurement	Acidified	Control
Water make-up, GPM	5	20
Total water volume used, gallons	6,720	26,520
Average B.O.D., ppm	6,034	742
Total B.O.D. discharged, pounds	118	170

2.232 INSTALLATION OF pH CONTROL SYSTEMS

The components of pH control systems include:

pH recorder (or indicator)/controller
plastic pH electrode (probe)
fiberglass or plastic tank
pneumatic or solenoid valve
or chemical feed pump

Several models of pH controllers, either with recording and/or indicating capabilities, are commercially available. The controller can be situated in close proximity to the system or in a remote area, whichever is more convenient.

Plastic or plastic-encased electrodes should be used to eliminate the hazard of glass fragments in food products. A plastic electrode can be immersed directly into an open flume or tank within the recirculation system. However, care should be taken to position the unit in such a manner as to minimize jostling by the conveyed commodity. An ideal position is at the point just prior to the introduction of commodity into the system.

A fiberglass or plastic tank with removable cover is ideally suited for storage of the acid solution. Citric or other suitable organic acids are recommended for most systems. Food-grade hydrochloric or phosphoric acid may be used if corrosion is not of concern, such as in an all-plastic system with acid-resistant pumps. The concentration of the acid solution should be adjusted so that the container will require refilling on a regular but minimal schedule, such as once per day or once per shift. CAUTION: When diluting concentrated acid solutions, always pour the acid into water; never pour water into concentrated acids.

TABLE 2.18

pH CONTROL OF FRUIT PUMPING WATER

	Relative Bacterial Count		pH		Temp °F	
Time of Sampling	Test System	Cont. System	Test System	Cont. System	Test System	Cont. System
6 a.m.	0.5	6	4.4	7.6	67	67
8 a.m.	63	138	4.1	7.2	72	70
10 a.m.	72	226	3.9	7.3	75	72
12 noon	39	106	3.8	7.4	72	70
2 p.m.	84	137	3.9	7.4	74	70
4 p.m.	61	111	4.0	7.4	76	72
6 p.m.	97	60	3.9	7.7	76	70
8 p.m.	41	82	3.8	7.4	75	71
10 p.m.	67	80	3.9	7.2	76	72
12 midnight	13	22	3.8	7.5	75	69
2 a.m.	2	59	3.8	7.4	74	69
4 a.m.	17	9	3.8	7.3	75	71

TABLE 2.19

CITRIC ACID CONSUMPTION AT VARIOUS FRESH WATER FLOW RATES

Flow in gallons per hour	lbs citric acid added per hour
65	2.1
160	2.3
220	2.4
330	2.8
420	3.1
560	3.2
700	3.6

If the acid tank can be situated so that the solution can be gravity-fed into the system, a solenoid or pneumatic valve can be used to control acidification. If the tank must be placed below the water level, a chemical feed pump with appropriate check valves must be used. In either case, the end of the acid feed line should be positioned below the water level in a flume or tank. The point of acid addition should be downstream from the electrode so that adequate mixing will occur before the pH of the recirculated water is measured.

Fresh water addition into the system should be controlled by a properly installed float-actuated valve. If continuous addition of water is deemed desirable, the rate of addition should be minimal. In some situations, product fragments and other debris may tend to accumulate within the system. A screening device incorporated into the return water line will facilitate removal of such objectionable materials and extend the usability of the recirculated water.

Although microbial growth can be effectively controlled in an acidified system, it is important to insure that the system does not contain "dead ends" or blind spots which may provide favorable harbors for microorganisms.

2.24 Other Control Methods

2.241 OZONATION

Ozone, or triatomic oxygen (O_3), is the most reactive form of oxygen and is considered to be the strongest oxidizing agent known. As such, it is a powerful germicide when used for water treatment; it has been widely used for this purpose in Europe, but only limitedly in this country. The use of ozone for maintaining sanitary conditions of water in the canning industry has been reported (958).

Ozone is generated by passing dry air or pure oxygen between two plate electrodes connected to high-voltage alternating current – several models of ozone generators are commercially available. The application of gaseous ozone to water is termed ozonation. Because of its instability, ozone residuals in water quickly dissipate. The germicidal effectiveness of ozone is therefore dependent on immediate and thorough contact with the water to be treated; its effectiveness is markedly reduced by the presence of organic matter with which it readily reacts. The reactiveness of ozone with organic matter has proven very useful in correcting taste and odor problems associated with raw water supplies.

Ozonation Control

The determination of ozone residuals needs to be performed immediately since samples cannot be preserved or stored, owing to the instability of the residual. The existence of ozone residuals of even less than 0.1 mg/l at the outlet of the ozonation chamber is generally effective for disinfection; therefore, the demonstration of an ozone residual in the water is generally sufficient. For other purposes, perhaps as much as 0.2 mg/l may be necessary.

Three methods are prescribed for the determination of ozone in water. The iodometric method is quantitative, subject to the fewest interferences, and capable of good precision. The method can also be used for the determination of ozone in the air by absorption of the ozone in iodide solution.

The orthotolidine-manganese sulfate method, generally abbreviated OTM, is semiquantitative. It is subject to relatively slight interference from other common oxidants.

The orthotolidine-arsenite method, usually designated OTA, is largely qualitative because of its liability to interference. However, it is useful for such control purposes as determinations at the outlet of the ozonation chamber, and would suffice for in-plant operations at food processing plants.

Procedures are described fully in *Standard Methods* and reference is made to the latest edition of that publication for details.[1] For processors that may be interested in maximum control, the ozone concentration in water or air can also be determined continuously by photometric instruments.

2.242 ULTRAVIOLET RADIATION

The use of ultraviolet radiation for germicidal purposes requires direct exposure of microorganisms to the ultraviolet source. Its effectiveness is a function of the intensity of transmission and the duration of exposure. Ultraviolet radiation is transmitted well in distilled water but is markedly absorbed by salts and organic substances in aqueous solution. Therefore, its use for disinfection of water is limited to treatment of raw water supplies.

Commercial ultraviolet water sterilizers are available from several manufacturers. These units offer the advantage of continuous or intermittent throughputs without the need for storage tanks or holding times. Modular units can provide treatment for a wide range of flows.

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[1] "Standard Methods for the Examination of Water and Wastewater," 14th ed. American Public Health Association, Inc., New York, N.Y. (1976).

2.3

IN-PLANT HANDLING OF SOLID WASTES

Procedures for keeping plants clean and sanitary include removal of spilled produce and other solid refuse from equipment, floors, and other processing facilities. The management program which is followed for handling these residual materials will have a substantial effect on the hydraulic and organic loadings of the wastewater effluent.

Solid wastes from food canning and freezing operations generally fit into two categories: non-food refuse and food residuals. The first includes damaged cans or containers, packaging materials, broken glass, discarded paper, broken pallets, and other similar inert materials. The second category, which represents the major quantity of solid waste, includes all non-usable items of raw materials procured for processing, such as damaged and cull whole fruits and vegetables, seeds, stems, leaves, skin or peel, and other degradable materials which are removed in processing.

Procedures for handling food residuals significantly influence the characteristics of the plant effluent, while normal handling procedures for non-food wastes have little or no effect upon wastewater. Therefore, emphasis in the following discussions is placed on methods for handling food wastes within a plant in a manner that will minimize the generation of water pollutants. The total concept of solid wastes management is discussed in Section 5.

2.31 Management of Food Residuals

2.311 HANDLING METHODS

In-plant handling of food processing residuals is not unlike the handling of raw products (see Section 2.113, Product Conveying). As in the case of raw products, food residuals may be handled or transported in containers, by mechanical or pneumatic conveyors, or hydraulically in flumes or, unlike raw product, in floor gutters. Containers which are commonly used include pans, barrels, bins or boxes, and portable metal hoppers. Mechanical conveyors include belts, vibrating troughs or tables, drag chains, and screw or auger conveyors. Pneumatic conveyors, which have recently been improved to handle bulk items, are available either as positive or negative pressure systems.

The greatest impact of food residuals on the wastewater effluent occurs when these solid wastes are hydraulically handled. Not only is a large volume of water required to transport waste materials in flumes and gutters, but the soluble organic matter which is washed or leached from the wastes into the water creates wastewater streams with extremely high organic loads. Elimination or minimization of these wastewater sources will measurably contribute to waste reduction programs.

The properties of solid waste (as determined by the size of particles, density, fluidity and quantity), as well as the physical layout of the processing plant, determine the method best suited for handling waste materials. In the interest of minimizing wastewater loads, hydraulic systems should be avoided whenever possible; where such systems are unavoidable reclaimed water, *never* fresh water, should be used. Alternate methods for handling residuals from various processing operations are discussed in the following section and summarized in Table 2.20.

2.312 RESIDUALS FROM SPECIFIC OPERATIONS

In a recent survey of the canning and freezing industry[1], information regarding current practices for in-plant handling

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[1] Katsuyama, A. M., N. A. Olson, R. L. Quirk, and W. A. Mercer. "Solid Waste Management in the Food Processing Industry." U.S. Environmental Protection Agency Publ. No. SW-42C-73 (NTIS. No. PB-219-019). 1973.

TABLE 2.20

METHODS SUITABLE FOR IN-PLANT HANDLING OF FOOD RESIDUALS

Source of Residuals	HANDLING PROCEDURES							
	Container	Conveyors					Pneumatic	Hydraulic*
		Belt	Mesh	Drag	Screw	Vibrate		
Dry Cleaning	X	X	X	X	X	X	X	
Washing	X		X					
Initial Sort	X	X	X	X	X	X	X	
Size Grading	X	X	X	X	X	X	X	
Trimming	X	X		X	X	X	X	
Cutting, Slicing, Dicing	X	X			X	X	X	
Peeling		X			X			X
Pitting	X	X		X	X	X	X	
Final Sort	X	X		X	X	X	X	
Pulping, Pressing	X	X		X	X	X	X	
Plant Cleaning	X	X		X	X	X	X	

*separate pumping system

of fruit and vegetable residuals were elicited (Table 2.21). The frequency of handling food residuals in water was almost twice that of dry handling. Although residuals from some operations physically necessitate wet conveying (such as mud from washers or peel from chemical peelers), solid wastes from many sources can readily be handled dry (Figure 2.23).

2.3121 Dry Cleaning

Many products are initially "dry cleaned" to remove readily separable extraneous materials which are inadvertently mixed with the delivered produce. Equipment used for this purpose include revolving or vibrating coarse screens to remove sand from spinach and other leafy greens and dirt clods from root vegetables, roller conveyors to separate leaves from tree fruits, and air cleaners to remove loose husks and leaves from corn and vines from green beans and peas.

Materials removed in dry cleaning operations can readily be handled dry. When the quantity of material removed is relatively small, containers, such as bins or portable hoppers, can be used to accumulate the solid waste. If the material quantity is large, equipment should be provided to continuously remove the waste from the operation and to convey it to an appropriate on-site storage area; belt, screw, and drag chain conveyors, as well as pneumatic systems are quite suitable for most types of wastes removed in this operation. Provisions for dry handling these materials eliminate the need for transport water and will reduce the organic load (primarily the settleable and suspended solids content) which would be generated by hydraulic conveying.

TABLE 2.21

IN-PLANT HANDLING METHODS FOR FRUIT AND VEGETABLE RESIDUALS

Waste Source	In-plant Handling Method*			
	Containers	Dry Convey	Wet Convey	Gutter
Dry Cleaning	27	36	7	33
Washing	13	0	12	82
Initial Sort	35	17	11	48
Size Grading	15	40	10	36
Trimming	16	38	12	37
Cutting, Slicing Dicing	11	42	7	40
Peeling	0	9	6	85
Quality Grading	7	0	7	86
Pitting	7	15	78	7
Final Sort	29	8	8	63
Pulping, Pressing	16	39	6	51

*Percent each category reportedly used. Since two or more methods are used in many plants, the totals exceed 100%.

2.3122 Washing

The initial washing of raw product is primarily to remove dust and dirt adhering to the produce. These become mixed in the water as settleable or suspended solids and can be transported from the operation only in water. However, other extraneous materials, such as leaves and vines, often accumulate as floating debris in wash tanks and flumes. These waste materials should be skimmed from the water, either manually or

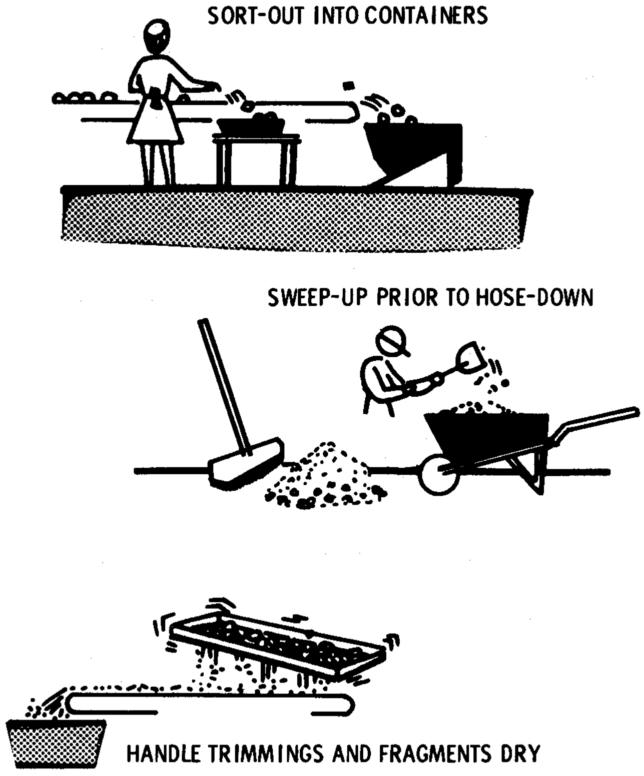

Figure 2.23. Dry handling food residuals.

by mesh belt or other skimming devices, and deposited into large containers Preventing these materials from entering the gutter system will minimize the volume of water required to transport wastes generated at this operation.

Intermediate and final washing of prepared product are normally provided to remove fragments and unwanted components (such as peel and seeds) from the primary product flow. The materials removed in such operations are frequently transported in the washwater generated at these points. However, when the water from these operations is recovered for reuse (see Section 2.12, In-plant Reuse of Water), removal of these materials from the water is desirable. Screens may be used for this purpose. When solid materials are so separated, dry handling procedures should be provided thereafter.

Containers are generally suitable since only small quantities of solid wastes are removed; mechanical or pneumatic conveyors may be required if the quantities are large.

2.3123 Size Grading

Although most products are classified into various size ranges, the size grading operation does not generate a large quantity of residuals from most products. However, some leaves, stems, crushed and undersized product and similar materials are normally separated from the usable product at this point. These materials should be collected in large containers or transported by mechanical or pneumatic conveyors, thereby eliminating the need for water and preventing the generation of an organic load due to leaching of soluble matter.

2.3124 Sorting (Inspecting), Trimming

Sorting and trimming operations involve manual removal of unusable materials from the product flow. In the sorting operation, sometimes referred to as inspecting or picking, cull and other unusable whole units are removed; in the trimming operation, only blemished, bruised or over-ripe segments are manually cut from whole units.

Solid residuals from both operations will contribute significantly to the organic load if placed in water. Therefore, these materials should be handled dry. When belt conveyors are used to convey the raw products as they are being inspected, the lower return belt is frequently used to transport the rejected materials or trimmings away from the processing area. Alternatively, these materials may be manually placed into hoppers of a pneumatic conveying system or into containers, such as pans, boxes, or barrels.

When the product being inspected consists of relatively small particles (such as peas, cut corn and diced produce), specially-designed pneumatic equipment is available to assist in removing unusable material. This equipment is similar to a hose and nozzle of a home vacuum cleaner; the system will transport removed materials to an outside storage facility.

2.3125 Cutting, Slicing, Dicing

Many products are cut or otherwise reduced in size by highly automated equipment. For example, green beans are snipped, cut or sliced; fruits are sliced or diced; root vegetables are sliced into several styles or diced. Each of these operations produce undesirable fragments of product which are normally separated from the desired material. The small bits and pieces are most frequently removed by rotating or vibrating screens, often with the aid of water. The high percentage of exposed surface of inner tissues in cut pieces results in rapid leaching of soluble organic matter into water. Therefore, when cut fragments are hydraulically conveyed, the resulting wastewater will contain a very high organic load. For this reason, it is highly desirable to handle such materials in containers or with mechanical or pneumatic conveyors.

2.3126 Peeling

Several types of equipment are used to peel a variety of fruits and vegetables. The peelers are classified as: (1) steam peelers, which are used mainly for carrots and other root vegetables; (2) mechanical peelers, such as mechanical knives for fruits and abrasive peelers for root crops. and (3) chemical peelers for fruits and vegetables.

Steam and conventional chemical peelers. Steam peelers produce finely divided particles of solid waste which are difficult to separate from water. The solid waste from conventional chemical peelers, wherein water sprays are used to remove peel material, are also finely divided. In both of these situations the peel material must be discharged with the liquid effluent, thereby offering no alternatives by which the organic load may be reduced.

Mechanical knife peelers. Mechanical knife peelers, which may be equipped with coring devices, are widely used to pare apples and pears. The peel material is removed as large discrete particles; the cores, as cylindrical "plugs". These materials are normally separated from the peeled fruit by the machines and can readily be collected and transported on a separate conveyor. Since these materials contain soluble organic matter which will be readily leached into water, use of hydraulic systems should be avoided. Maximum yields for by-products, especially with apples, will be realized by dry handling these materials.

Abrasive peelers. Abrasive peelers generate a slurried waste material, the consistency of which is largely dependent upon the quantity of water used in the peeling equipment. Such slurries have extremely high BOD and suspended solids contents. Elimination of these materials from discharged wastewater will result in a measurable reduction in the organic load.

The peel slurry can be collected in a hopper or a catch pan situated below the peeler. The consistency of the slurry will enable pumping of the collected materials to the waste storage area. By mixing the peel slurry with other food residuals, the free moisture content of the blend will still enable disposition of the materials by normal means. However, the consistency of the peel material should be maintained as thick as practicable by minimizing water usage in the peelers, thereby minimizing the quantity of free moisture in the residual blend.

Dry caustic peelers. The dry caustic peeling process was developed to reduce the amount of pollutants generated by potato processing operations.[1,2] (Also see Section 2.1144,

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1. Graham, R. P., C. C. Huxsoll, M. R. Hart, M. L. Weaver, and A. I. Morgan, Jr. "Dry Caustic Peeling of Potatoes, "*Food Tech, 23*(2): 195 (Feb. 1969).
2. Cyr, J. W., "Progress Report. Study of Dry Caustic vs. Conventional Caustic Peeling and Effect on Waste Disposal," *Proc. 2nd National Symposium on Food Processing Wastes,* Denver, Colo. (March 1971) pp 129-136.

Chemical Peelers.) A direct comparison between this method and the conventional caustic peeling process indicated substantial reductions in both the quantity of water consumed and the quantity of solids present were achieved. This is directly attributable to the ability to segregate and separately handle the peel material.

The rubber discs which are used to "wipe" the peel from potatoes have been adapted for removal of caustic treated peel from other commodities, namely, peaches, beets and sweet potatoes. Peel material so removed can be collected in a hopper and pumped directly to the waste storage area, or may be collected and transported on a conveyor belt positioned directly beneath the peeler. By preventing these "solid" waste materials from entering the wastewater system, a substantial contribution to the organic load is avoided.

2.3127 Pitting

Automated pitting machines are used to destone such fruits as apricots, cherries, olives, peaches and plums. The pits removed by this equipment generally have fruit flesh adhering. If placed into water, this material will contribute significantly to the organic load.

Some pitters separately discharge the stones and the fruit. In such situations the pits should be collected either in large containers or, preferably, on a separate conveyor and transported to the waste storage area. When the pitting equipment does not separate the materials, the pits are generally separated from the fruit by revolving or shaker screens. The pits removed by the screens should then be handled as above.

2.3128 Pulping, Extracting

Pulping, juice extracting, and finishing equipment are used to produce fruit and vegetable nectars, purees, and juices by mechanically compressing raw products against screens or perforated plates. The waste material ejected from these types of apparatus is called roughage or pomace, consisting of stems, skin, seeds, fiber and other coarse components of the raw product.

Although much of the liquid is extracted by these processes, the ejected materials still contain soluble organic matter. When these materials are placed into water, the soluble organic matter creates a high pollutional load. A study conducted with tomato pomace revealed that the BOD load generated by placing this material into water was equivalent to three percent of the wet weight of the pomace (3 pounds of BOD for each 100 pounds of pomace).[1] Therefore, it is mandatory that these materials be handled dry.

Pomace from pulpers, extractors and finishers can easily be collected and transported on belt, drag or screw conveyors. Pneumatic conveyors are also successfully employed. When the quantity of ejected material is relatively small, the material can be collected in bins or portable hoppers situated at the waste discharge end of the equipment. Any of these waste handling procedures will prevent the creation of a significant organic load.

2.3129 Plant Cleaning.

As discussed in Section 2.116, the procedures normally followed for plant cleanup consume large volumes of water. Much of the water is used simply to flush solid waste materials from equipment and floors into the gutter system. Additional quantities of water may then be required to transport the solid materials to the waste storage area. This practice not only adds to the hydraulic load of the plant effluent, but will also add to the organic load by the leaching of soluble matter from the waste materials. Wastewater loadings attributable to plant cleanup can be minimized by altering the cleanup procedure.

Prior to the use of detergents and water to clean the processing equipment and floors, food residuals should be manually placed into suitable receptacles. Materials which tend to accumulate in equipment should be brushed or scraped away; materials on the floor should be swept and shoveled into containers. Alternatively, pneumatic conveying systems may be equipped with special attachments which can be used to vacuum-clean processing areas. A dry pre-cleanup procedure is an essential part of a successful waste reduction and prevention program.

2.32 Management of Non-food Residuals

Non-food residuals, such as containers, paper and scrap lumber, are most readily handled in barrels, bins and other receptacles. Therefore, most plants provide containers for those areas in which such wastes are generated. Although these materials will generally not contribute to wastewater loadings, their introduction into wastewater streams may indirectly influence the quantity of pollutants discharged.

For example, paper, lumber and scrap metal can clog pipelines, stop pumps and damage waste screens. Blockages in waste pumping system may cause overflows of wastewater which can inadvertently enter receiving streams; damaged screens will permit the discharge of large particles of solid materials which will unnecessarily burden wastewater treatment systems. For these reasons, it is important that non-food residuals be handled in such a manner as to preclude their entry into the wastewater collection system.

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[1] Rose, W. W., and A. M. Katsuyama, "In-plant Water and Waste Management," *Proc. 1972 Research Highlights Meeting.* National Canners Assn., Berkeley, California (November 1972).

2.4

WASTE CONTROL CONSIDERATIONS

Fundamental to and a most important factor in the development and maintenance of an effective waste management program in any food plant is the assignment of responsibility for the successful operation of the program to a specified individual. Unless that person is given absolute responsibility, and unless the plant staff is aware of that assigned responsibility, a coordinated productive program for preventing and controlling wastes is unlikely to result. The person having such responsibility must also have authority to train and supervise employees whose activities affect waste production and disposal.

A total waste management concept must include coordinated efforts between those responsible for raw product procurement, for production management, and for plant cleaning and maintenance. Considerations which are important when developing a waste management program are outlined below. Relevancy of single factors will vary depending upon the product being processed and the size, nature, and internal organization of the food processing operation.

2.41 Management Considerations

1. Selection or development of a processing plan which optimizes the utilization of the raw commodity.
2. Appointment and delegation of authority to appropriately qualified "waste management personnel."
3. Employee awareness and training programs. Possible use of incentives to encourage adoption of waste reduction practices.
4. Maintenance and use of records.
   a. Utilization values of raw product as related to quality and other raw product characteristics.
   b. Water volume used by process activity.
   c. Total and area waste volumes.
   d. Process down-times and their causes (equipment failure, personnel negligence, other).
   e. BOD and/or COD of effluent.
   f. Other waste data essential to meet disposal requirements.

2.42 Product Preprocessing Considerations

1. Planning and management of raw product growing schedules and practices to reduce process wastes.
   a. Select varieties having:
      - high utilization values
      - disease and insect resistance
      - uniform maturation, size and shape
      - suitable quality for machine harvesting
   b. Avoid when possible using pesticides which subsequently prohibit the utilization of potential solid wastes as feed for livestock.
   c. Use appropriate pesticides to maintain the raw commodity relatively free of culls, and insect and disease lesions which require trimming and sorting.
   d. Avoid, when possible, circumstances resulting in supply gluts which exceed the process capacities.
2. Harvesting the commodity at optimum maturity. Some products harvested at either a pre- or post-mature condition are less acceptable for processing, resulting in lower utilization values and increased waste volume.
3. Synchronization of harvesting, transporting,and processing operations to avoid delays which result in raw quality deterioration, lower utilization, and increased waste volume.
4. Selection and management of harvesting equipment and operations to obtain:
   a. The best feasible separation and disposition of non-food tissues, soil and other debris inthe field.
   b. A clean raw product with minimum bruising.
   c. When feasible, culling or sorting of raw product to

reduce or eliminate delivery of unacceptable raw products to the processing plants.

5. Selection and management of handling systems which are economical, convenient, and which lend to mechanization and minimize bruising. Piling or dropping practices which cause bruising should be avoided.
6. Selection and management of transportation systems to minimize losses in quality.
7. Controlling environmental factors.
   a. In some cases with highly perishable plant tissue, it may be necessary to control raw product temperature while transporting between harvest and processing sites.
   b. If cold storage is desirable or practiced before processing, proper consideration should be given to controlling storage variables.
      - maturity
      - curing treatments
      - temperature
      - humidity
      - air composition
      - chemical treatments to control sprouting, storage diseases, rodents, and insect infestations.

2.43 Processing Considerations

1. Balancing processing rate and equipment capacities to prevent bottlenecks, overflows, spillage, and leakage which cause product or quality losses from the process line. These problems are often associated with undersized or antiquated equipment such as holding tanks, washers, pasteurizers, blanchers, conveyors, fillers, closers; sometimes such problems may be caused by a lack of adequate in-line holding stations or accumulators.
2. Selection of processing methods and equipment systems to optimize utilization, and thus reduce waste.
   a. Product cleaning and handling systems.
      (1) Use dry-cleaning systems where practical.
         - perforated-drum tumblers
         - compressed air or mechanical agitation devices
         - air-blowers
         - roller conveyors
      (2) High-pressure, low-volume water sprays for cleaning.
      (3) Chemical cleaning aids.
      (4) Dry conveyors instead of flumes.
   b. Peeling and extraction equipment.
      (1) Recovery of raw product.
      (2) Effects on quality, i.e., flavor and color degradation, texture, burn-on.
      (3) Effects on wastes which have potential in recycling feeding systems (acid or alkali treatments).
      (4) Adjustment control of equipment to raw product variables.
   c. General equipment design to eliminate:
      (1) Spillage from process line; particularly with materials handling equipment and at transfer points between two unit operations.
      (2) Mechanical bruising.
   d. Appropriate automatic process equipment controls.
      (1) Effective automatic control systems on all heating and flow-regulating pumps to assist in preventing under- and over-heating with pasteurization and sterilization equipment.
      (2) Automatic shut-off valves on all water outlets not regulated by process controls.
      (3) Automatic level regulators in holding tanks and vats to prevent overflows.
      (4) Integrated equipment master control switches to enable a single operator to turn off multiple equipment operations in case of a jam-up. For example, in the case of a sudden breakdown with a filler, closer, pasteurizer or automatic sterilizer, any area operator should be able to turn off with one switch all equipment back to a holding or accumulating station. For convenience, multiple master switches around integrated equipment systems may be necessary.
   e. Preventive equipment maintenance practices to reduce operational breakdowns. During regular processing schedules, equipment repair delays are extremely costly because of idle labor, production losses, possible losses in product quality, and increases in wastes generated.

      In addition to the skills of good mechanics, an effective preventive maintenance program includes complete records of equipment failures. Subsequently, it includes the formation of preventive maintenance schedules designed to replace or service equipment parts before they normally become the cause of operational downtime.

2.44 Plant Design, Waste Management and Cleanup Considerations

1. Separation of solid and liquid wastes.
   a. Continuous solid waste collection, holding, or dry removal systems at each location in the process line where solid wastes are generated. Additionally, it may be desirable to segregate types of solid wastes, particularly those having potential for resue.
   b. Where practical, area shielding and floor curbing to restrict scattering or combining of solid and liquid wastes. These features may also reduce labor and water needed for cleanup.
2. Proper installation and operation of screens, filters, or centrifugal separators to remove suspended solids from plant effluent.
3. Plant and equipment cleanup practices.
   a. Dry clean equipment and floor areas where solid wastes accumulate before hosing with water. Dry cleaning tools include, among others, vacuums, compressed air streams, floor brooms and scoops.
   b. Consider the use of chemical cleaning aids and high pressure steam and water on equipment and floors to reduce the water volume needed in cleanup.

Though the foregoing outline may not fully cover considerations pertinent to conducting an effective program for preventing and reducing wastes, it can serve as a guide to items that should be given attention by food processors in establishing and maintaining a comprehensive waste management program.

SECTION 3

MONITORING LIQUID WASTE FLOWS

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SECTION 3
MONITORING LIQUID WASTE FLOWS

LIST OF FIGURES

LIST OF TABLES

3.1

SIGNIFICANCE OF IN-PLANT SURVEY AND MONITORING PROGRAMS

Effective planning and implementation of water conservation and/or waste treatment and disposal programs must be based on factual data accumulated from each food processing plant. The accumulation of all necessary information can be achieved only through a carefully planned in-plant survey program. Some of the facts which must be developed during such a survey are:

1. The patterns of flow of both fresh water and wastewater streams within the plant.
2. The volumes of water utilized and discharged by each unit operation.
3. The pollutional load generated by each unit operation.
4. The hydraulic and organic load of the total plant effluent.

The operation and maintenance of waste prevention and reduction programs (Section 2) and wastewater treatment and disposal systems (Section 4) will require continuous accumulation of much of this information through a monitoring program. The data collected from an intensive in-plant survey will prove invaluable for designing a routine monitoring program.

3.11 In-plant Survey

The information collected during in-plant surveys is especially useful for two purposes:

1. For use in an in-plant waste control program where each processing unit will be critically evaluated and an attempt made to reduce waste loads. Operations in which water is being used in excess will be quickly identified, enabling corrective measures to be taken to reduce these obvious sources of wastewater. Further reductions in water consumption, and hence, wastewater generation, will be possible through water reuse systems which can be efficiently designed with the data collected during the survey program.
2. For use in the design of a treatment facility which will adequately reduce all waste loads to the level required for discharge to a receiving stream. The data collected during the survey should include the physical and chemical characteristics of each waste stream. Relatively clean wastewater sources will then be identified and segregation and separate disposal arrangements or reuse systems can be considered for these streams. Waste streams containing sufficiently high concentrations of pollution-creating materials can be characterized and appropriate treatment systems designed for their disposal.

3.12 Monitoring Program

The primary purpose of a waste monitoring program is to provide information by which the operating efficiency of waste prevention and wastewater treatment programs can be evaluated. Thus, such a program is generally implemented for each water reuse system and each step of a treatment and disposal operation. Information regarding these systems is continuously gathered. Therefore, it is convenient to provide permanently installed equipment for measuring and recording flows, and for collecting representative samples of wastewater for laboratory analysis. Various types of equipment are discussed in the ensuing sections.

3.13 Program Procedures

The purposes of the two programs, as previously discussed, are somewhat different, although the basic information collected is essentially identical. The survey program is an intensive data-collecting project, which can be accomplished during a single season, whereas, the monitoring program is a continuous one for specific operations. Suggested procedures for each program are outlined below. The sections referred to will discuss in more detail the steps which can be followed to obtain the desired information.

In-plant Survey

1. Draw a map of the plant, locating all water supply lines and wastewater flows (Section 3.2).
2. Select methods of flow measurement and install measuring devices where necessary (Section 3.3).
3. Select sample collection sites and establish a sampling schedule (Section 3.4).
4. Determine laboratory analyses to be made and review test procedures to determine chemicals and equipment required (Section 3.5).
5. Proceed with the development of data.
6. Correlate production records (raw and finished products) to waste flows and laboratory results. Extrapolation of results will then be possible for future operating conditions.

Monitoring Program

1. Revise the map drawn for the survey to include any modifications which may have been made to the water and wastewater flows. Include existing waste treatment facilities.
2. Select appropriate monitoring points for each water reuse system which is in operation and collect samples for appropriate laboratory analysis.
3. Select appropriate monitoring points for each wastewater stream being discharged from the plant and at appropriate points in the existing waste treatment facility. Install flow measuring and recording devices at suitable locations.
4. Establish a sampling schedule which will assure the collection and analysis of samples at frequencies sufficient to detect and avert potential water pollution problems.
5. Keep permanent records of all data collected, including corresponding production records and waste treatment costs.

3.2

MAPPING PLANT WATER AND WASTE STREAMS

The initial step of a survey program is the mapping of all fresh water lines and wastewater gutters and conduits within the plant. Blueprint plans of the plant lay-out, if available, are ideal for this purpose. The pattern of flow of the water used in the plant should be traced from each source, through all operations which utilize water, to all points from which wastewater is discharged. The arrangement of the wastewater collection system should include directions of flow. A hypothetical water and wastewater map is presented in Figure 3.01. to illustrate how such a map might appear.

The water and wastewater map is extremely helpful for determining the points within the plant at which flow measuring devices should be installed and for selecting suitable sample collection sites. In the selection of both flow meter locations and sampling points, consideration should be given to:

1. The estimated hydraulic load from various operations, especially those in which large quantities of water may be unnecessarily used.
2. The anticipated relative strength of the wastewater stream.
3. Flows which are potentially suitable for reuse, coupled with the hydraulic and sanitation requirements of the operations for which water reuse is contemplated.

When the metering and sampling points have been selected, the sites should be identified by code and noted on the map, as illustrated in Figure 3.01.

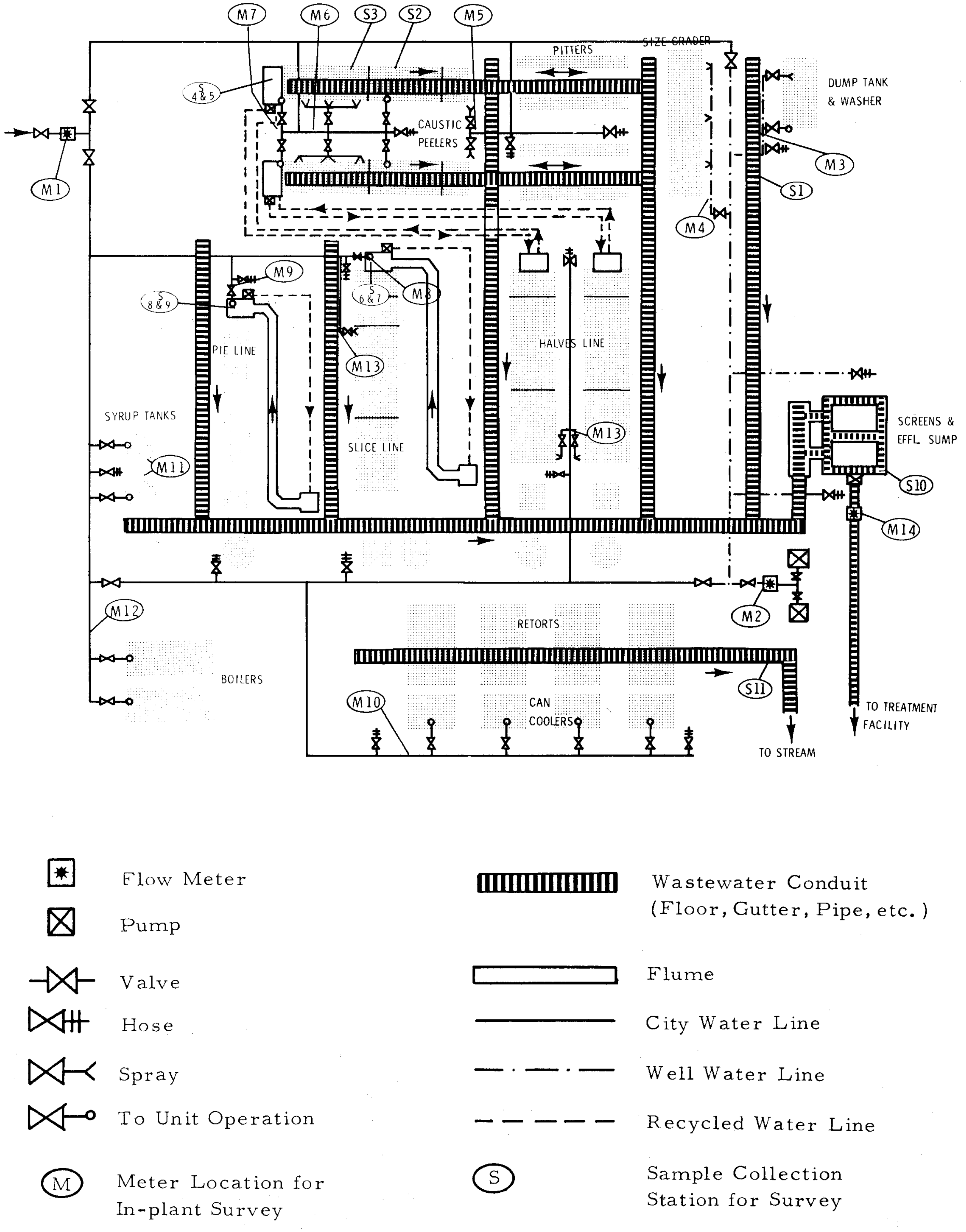


Figure 3.01. Hypothetical map of a peach processing plant.

Meter Locations

M1	City Line
M2	Well Pumps
M3	Dump Tank and Spray Washer
M4	Size Grader Lube Spray*
M5	Lube Sprays on Shaker to Peeler*
M6	Caustic Peeler and Rinse Sprays
M7	Halves Pumping System
M8	Flume System to Slice Line
M9	Flume System to Pie Line
M10	Can Coolers
M11	Syrup Tanks*
M12	Boilers
M13	Belt Lube Sprays*
M14	Plant Effluent

*Use Container and Stopwatch Method for Flow Measurement

Sampling Sites

S1	Dump Tank Overflow
S2	Caustic Peeling Solution (Prior to Discharge)
S3	Rinse Sprays
S4	Halves Pumping System Overflow
S5	Halves Pumping System (Prior to Discharge)
S6	Overflow from Flume to Slice Line
S7	Flume to Slice Line Prior to Discharge
S8	Overflow from Flume to Pie Line
S9	Flume to Pie Line Prior to Discharge
S10	Plant Effluent After Screening
S11	Can Cooling Water

3.3

METHODS FOR MEASURING FLOW

Selection of an appropriate method for the measurement of water used by unit operations or of flows in specific in-plant waste streams and in composite plant effluents is limited by the physical arrangement of each system. Some methods for measuring flows in various types of systems are discussed in this section.

Methods for measuring the quantity of water used by unit operations are discussed in Section 3.31. Determination of flows in various waste streams can be accomplished by several methods. The commonly employed systems, and hence, the choices of measuring techniques, are classified under three general categories:

1. Open channels (gutters, flumes, ditches) – Section 3.32
2. Partially-filled pipes (gravity-flow conduits) – Section 3.33
3. Pipes under pressure (pumping systems) – Section 3.35

Emphasis has been placed on methods which yield reliable estimates without necessitating expensive apparatus. These methods will prove satisfactory for in-plant survey programs, as discussed in Section 3.1. However, for successful conduct of waste treatment and disposal operations, permanent flow-metering and recording installations are recommended.

3.31 Volumes to Each Unit Operation

In-plant waste collection systems are often inaccessible or are arranged in such a manner that it is virtually impossible to segregate flows originating from separate operations. Under these conditions, the easiest means to determine the volume contribution from each operation to the composite plant effluent is to measure the volume of water used by each. However, caution should be exercised in the determination of flows by this method. Any portion of water from a unit operation which is reused in a separate operation must be noted and properly accounted for.

3.311 CONTAINER AND STOPWATCH

The simplest and least expensive method for measuring flows is by the container and stopwatch technique. Although this method is rather crude when compared to the equipment and devices discussed in the ensuing sections, reasonable estimates are obtainable. Flows are determined by recording the time required to fill a container of known volume. For greater accuracy, the following should be observed:

1. A stopwatch, rather than an ordinary clock, should be used.
2. Containers which require more than 10 seconds to fill should be used to minimize observational errors.

Calculate the capacity of rectangular or cylindrical containers by the following formulae:

1. Volume (gallons) of rectangular box $= \text{length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \times 7.48$ (1)

   or

   $$\frac{\text{length (in)} \times \text{width (in)} \times \text{depth (in)}}{231} \qquad (2)$$

2. Volume (gallons) of cylinder $= (\text{diameter, ft})^2 \times \text{depth (ft)} \times 5.87$ (3)

   or

   $$\frac{(\text{diameter, in})^2 \times \text{depth (in)}}{294} \qquad (4)$$

If an irregular-shaped container, such as a bucket, is used, its capacity may be determined as follows:

1. Weigh the empty container.
2. Fill the container with water and weigh again.
3. Calculate the capacity by:

$$\text{Volume (gallons)} = \frac{\text{filled weight (lbs)} - \text{empty weight (lbs)}}{8.34}$$

If water to an operation is from a single pipe, a container can readily be placed to collect the influent stream. If, however, the influent water is difficult to collect in a single container, as in the case of a bank of sprays, a suitable catch basin can be used to initially collect the water flow. The collected flow can then be diverted to the measuring container.

Determine the flow in the following manner.

1. If a catch basin is required, place it in a suitable position, taking care that water will not be lost over its sides.
2. Turn on on the water supply to the operation. Be certain that flow rates are as close to operating conditions as possible.
3. Place the container in position to collect *all* the water from the catch basin. Simultaneously start the timer (stopwatch).
4. When the measuring container has filled to capacity (or a predetermined level), immediately stop the timer.
5. For greatest accuracy, repeat the procedure several times and use the average interval to calculate the flow.
6. Calculation:

   Q, flow in gallons per minute (gpm) =

$$\frac{\text{Volume of container (gallons)}}{\text{Time required to fill (seconds)}} \times 60$$

3.312 WATER METERS

For convenience and greatest accuracy, the installation of meters on influent water lines is recommended. In-line water meters are available in a wide variety of sizes and flow ranges. Various types of such meters are discussed in the section concerned with measurement of flows in PIPES UNDER PRESSURE, Section 3.35.

3.32 Flows in Open Channels

Open channels are commonly used in food processing plants. These include flumes and gutters used for the hydraulic transport of product within the plant, as well as flumes, gutters and ditches used for the collection and transport of liquid waste streams within and away from the plant. The flow of water in these systems can be:

1. Estimated by measuring the depth and velocity of flow in the channel, or
2. Measured with the use of a suitable device, such as a weir or Parshall flume.

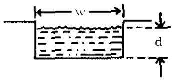
3.321 DEPTH AND VELOCITY OF FLOW METHOD

A reasonable estimate of the flow in an open channel can be derived from observation of the velocity, or rate of flow, within the channel and measurement of the cross-sectional area of the water along the stretch of the channel in which the rate of flow is observed. The rate of flow is estimated by recording the time required for a floating object to travel between two points of the channel.

The accuracy of results obtained by this method proved when:

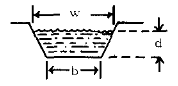
1. The flow in the channel is constant, and
2. The bottom and walls of the channel are smooth and of even dimensions along the section where the measurements are taken.

Measure the cross-sectional area (A) of the channel in one of the following manners.



1. For rectangular channels:

   A = width x depth



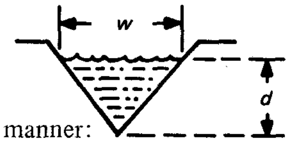
2. For trapezoidal channels:

$$A = \frac{(w + b)}{2} \times \text{depth}$$

where

w = width of channel at water surface

b = width of channel at the bottom



3. For triangular channels:

$$A = \frac{\text{width x depth}}{2}$$

Determine the flow in the following manner:

1. Select a straight portion of the channel, if possible of sufficient length to require at least 10 seconds for a float to traverse the distance.
2. Place a marker at each end of this stretch. Measure the distance between the two points.
3. Calculate the cross-sectional area of the channel as outlined above. If the dimensions of the channel are irregular, make several measurements along the selected length and use the average for calculation.
4. Place a float (a piece of wood or cork or an empty, sealed can) on the water at a distance slightly upstream from the first marker.
5. Using a stopwatch, time the interval required by the float to traverse the distance between the markers. Repeat several times and use the average for calculation.
6. Calculation:

$$Q\,(\text{gpm}) = \frac{\text{Area (ft}^2\text{) x length (ft)}}{t\ \text{(seconds)}} \times 449 \qquad (1)$$

or

$$Q\,(\text{gpm}) = \frac{\text{Area (in}^2\text{) x length (in)}}{t\ \text{(seconds)}} \times 0.26 \qquad (2)$$

3.322 WEIRS

A weir is an inexpensive device for measuring flows in open channels. As illustrated in Figure 3.02, a weir is simply a barrier or dam containing a recess or notch, through which water flows to fall freely to a level below the bottom of the recess or notch. The height of the water passing over the weir varies with the volume of water flowing in the stream. Thus, flows are determined by measuring the head (i.e., the depth of the stream between the bottom of the recess and the water surface) at an appropriate distance behind the weir (Figure 3.03).

Various shapes are used in the construction of these devices. The more common forms are V-notch, rectangular, and trapezoidal. Selection of a weir shape is determined by the flow rate and the dimensions of the channel. Tables 3.01, 3.02 and 3.03 are provided for the various types of weirs in common use. By referring to these tables a properly designed weir can be constructed in the following manner:

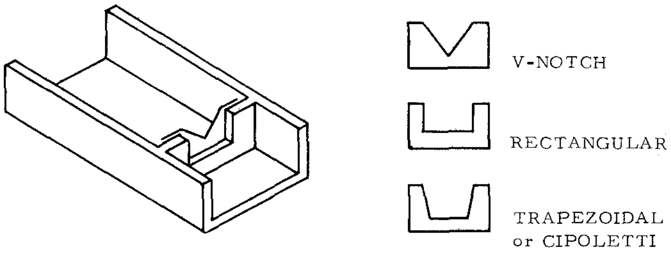


Figure 3.02. Common forms of weir plates.

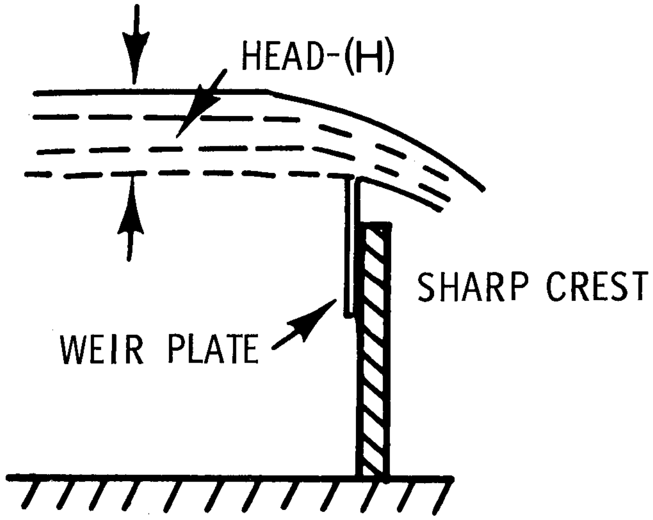
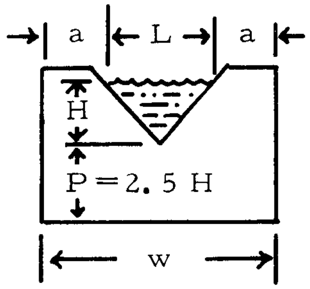


Figure 3.03. Flow over sharp-crested weir.

1. Estimate the maximum waste flow that can be expected. The depth-velocity or container and stopwatch methods are useful for this purpose.
2. Select one of the weir types and find the head over the weir corresponding to the estimated maximum flow by referring to the appropriate table.
3. The total depth for maximum flow should be at least 3.5 times H, the head as found in Step 2.
4. Compare this to the actual depth of the channel in which the flows are to be measured. Allow at least two inches to insure against flooding.
5. Check the lateral dimensions to see if the channel width fulfills the specifications for the type of weir selected:



   a. For a 90° V-notch weir the width of each end contraction, a, must be at least 1.5 times H. Thus, the width of the channel should be at least 4 times H.
   b. For a standard rectangular weir, the width of each end contraction, a, should be greater than 2.5 times H. Thus, w > 5 H + L.
   c. For rectangular weirs with modified end (trapezoidal) contractions, the width of each end contraction need only be large enough to permit the free passage of air between the walls of the channel and the flow of water passing over the weir.

The rectangular weir with modified end contractions appears to be the best design for general use since most gutters and flumes in food processing plants are too narrow to permit the use of a V-notch weir with the listed tables. However, this latter type is excellent for measurement of small flows.

Observation of the following points will increase the accuracy of the weir measurements.

1. The weir plate must be vertical and the top must be level.
2. The sides and bottom of the plate should be sealed to prevent leakage.

TABLE 3.01
DISCHARGE OVER 90° V-NOTCH WEIR

Note — Total width of two end contractions = 2a = 1.5L
where "a" = width of each contraction
"L" = width of water flowing over weir

Head (H) inches	Discharge gallons per minute (gpm)	Head (H) inches	Discharge gallons per minute (gpm)
1	2	9	555
1/4	4	1/4	594
1/2	6	1/2	632
3/4	9	3/4	684
2	12	10	725
1/4	17	1/2	815
1/2	24		
3/4	30	11	910
3	37	1/2	1040
1/4	45	12	1130
1/2	53	1/2	1250
3/4	65		
4	76	13	1380
1/4	88	1/2	1520
1/2	100	14	1650
3/4	114	1/2	1810
5	129	15	1970
1/4	149	1/2	2120
1/2	166		
3/4	183	16	2310
6	204	1/2	2480
1/4	225	17	2670
1/2	247	1/2	2880
3/4	276	18	3080
7	300	1/2	3290
1/4	332		
1/2	354	19	3530
3/4	383	1/2	3760
8	413	20	4000
1/4	451	1/2	4250
1/2	486	21	4500
3/4	520	1/2	4770

3. The weir can be of wood or metal. A metal plate bolted to the upstream side of a wood section will make a satisfactory weir. The crest should be 1/8" to 1/4" thick and sharp-edged. If the weir is thicker, the top should be beveled to this dimension on the downstream face.
4. The crest height, P, should be at least 2.5 times the maximum expected head.
5. The head should be measured at a point upstream from the weir, at a distance at least 4 times that of the maximum expected head. A staff gauge or rule, the zero mark of which is level with the crest of the weir, can be attached to the wall of the channel for this purpose.

3.323 PARSHALL FLUMES

The Parshall or venturi flume consists of a constricted portion, or throat, with a gradually contracting section leading to the throat and a gradually expanding section leading from it. The floor of the contracting section is level with the bottom of the open channel, the throat contains a downward-sloping

TABLE 3.02
DISCHARGE OVER RECTANGULAR WEIR WITH STANDARD END CONTRACTIONS

Note — "a" = width of each end contraction. It should be greater than 2.5 H

Head (H)	Discharge — Gallons per minute (gpm) Length of Weir (L) — Inches								
Inches	2	4	6	8	10	12	15	18	24
1/4	1	2	2	3	4	5	6	7	10
1/2	2	4	6	9	11	13	16	19	26
3/4	4	8	12	16	19	23	29	35	46
1	6	12	18	24	30	36	45	54	72
1/4		17	25	33	42	50	63	76	100
1/2		22	33	44	55	66	83	99	132
3/4		28	42	55	69	83	104	124	166
2		34	51	68	85	101	127	152	202
1/4			61	81	101	121	152	183	242
1/2			71	95	118	142	178	213	284
3/4			82	109	136	164	205	246	328
3			93	124	155	187	233	280	374
1/4				140	176	210	262	316	420
1/2				157	197	235	294	353	470
3/4				174	218	261	326	392	522
4				190	239	287	358	321	574
1/4					262	314	393	472	628
1/2					285	343	429	515	686
3/4					310	374	465	559	748
5					334	403	500	605	806
1/4						433	540	650	866
1/2						464	580	695	928
3/4						496	620	745	992
6						528	660	791	1050
1/4							701	842	1120
1/2							743	893	1190
3/4							785	945	1890
7							830	1000	1330
1/4							875	1050	1400
1/2							920	1100	1470
3/4								1160	1540
8								1210	1620
1/4								1270	1700
1/2								1340	1780
3/4								1400	1860

floor, and the expanding section has a rising floor which is slightly lower than the original section (Figure 3.04).

The velocity of the water flowing into the constricted throat increases, thereby resulting in a decrease in the depth of the water as explained by the Venturi principle. The difference in the depth between the water level at the entrance to the flume, H_a, and the level at the throat, H_b, is a measure of the flow through the unit. Parshall flumes are designed in such a manner as to require the measurement of only one depth, or head (H_a), at a prescribed point in the contracting section of the unit. Visual indicators and automatic recording instruments are also available for these units.

Parshall flumes are excellent devices for measuring plant effluent volumes and are widely used for this purpose. These have the advantage over weirs of not greatly affecting flows, thereby avoiding flooding caused by back-up of water in the channel. They are also relatively unaffected by suspended material. A table (Figure 3.04) and a graph (Figure 3.05) are provided to assist in the selection of a suitably sized unit.

TABLE 3.03
DISCHARGE OVER RECTANGULAR WEIR WITH MODIFIED END CONTRACTIONS

Note — "a" = width of end contractions - large enough to permit free passage of air down side of weir plate

Head (H)	Discharge — Gallons per minute (gpm) Length of Weir (L) — Inches								
Inches	2	4	6	8	10	12	15	18	24
1/4	1	1	2	3	3	4	5	6	8
1/2	2	4	6	8	10	12	14	17	23
3/4	4	7	11	14	18	21	26	32	42
1	5	11	16	22	27	32	41	49	65
1/4	8	15	23	30	38	45	57	68	91
1/2	10	20	30	40	50	74	89	89	119
3/4	13	25	38	50	62	75	94	112	150
2	15	31	46	61	77	92	115	138	184
1/4	18	36	55	73	91	109	137	164	218
1/2	21	43	64	85	107	128	160	192	256
3/4	25	49	74	98	123	148	185	222	296
3	28	56	84	112	140	168	210	252	336
1/4	32	63	95	126	158	189	237	285	378
1/2	35	70	106	141	175	211	264	316	422
3/4	39	78	118	157	196	235	294	353	470
4	43	88	133	177	222	256	333	399	512
1/4	47	94	142	189	236	283	354	425	566
1/2	52	103	155	207	259	310	387	465	620
3/4	56	112	168	224	280	335	419	502	670
5	60	120	181	242	302	362	453	544	724
1/4	65	128	195	260	325	389	486	583	778
1/2	70	138	209	279	349	418	522	627	836
3/4	74	149	223	298	372	446	558	670	892
6	79	159	238	318	397	476	595	715	952
1/4		169	253	337	422	506	633	760	1010
1/2		179	268	357	447	535	669	803	1070
3/4		189	283	378	473	566	707	850	1130
7		200	299	400	500	598	749	898	1200
1/4		210	315	420	526	630	788	945	1260
1/2		222	332	444	554	664	830	996	1330
3/4		232	348	464	581	696	870	1045	1390

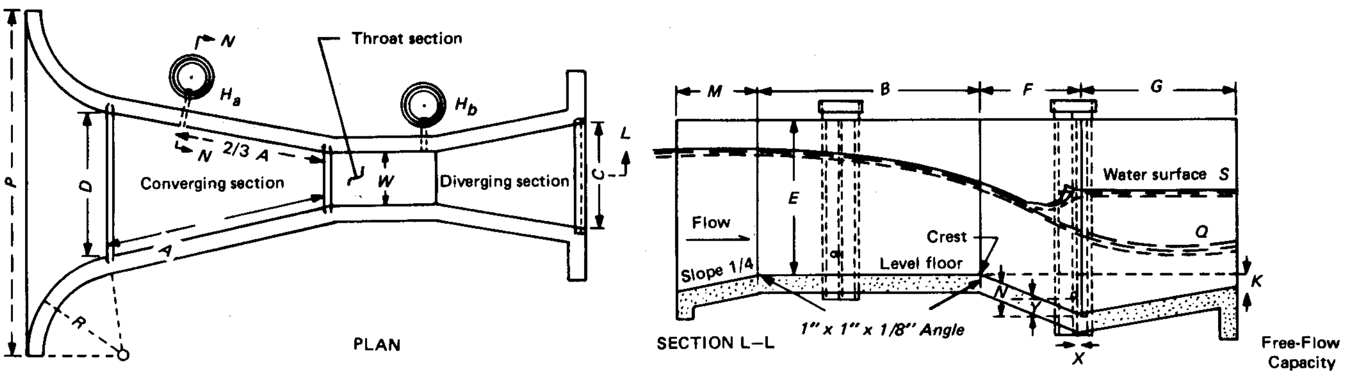
3.324 PALMER-BOWLUS METERING FLUMES

For round-bottom channels or pipelines accessible through manholes or other openings, the Palmer-Bowlus metering flume is an inexpensive and easily installed device. The Palmer-Bowlus flume may be nothing more than a level section of flooring placed into a waste flow, which is a major advantage over the Parshall flume. The length of the flooring should be approximately the same as the diameter of the conduit. The flume is positioned at the bottom of the conduit. It provides a slight restriction or throat which creates an upstream head of water.

Figure 3.06 shows two possible forms of the Palmer-Bowlus flume. The materials used to build the flume may be cast iron, stainless steel, fiberglass or concrete. This type of flume is easily installed in existing waste flows as no drop in head is required. The critical depth will be at the top of the level flooring. The flow through a Palmer-Bowlus flume may be represented by the following equation:

At critical flow:

$$\frac{Q^2}{g} = \frac{A_c^3}{b} \quad \text{and} \quad \frac{V_c^2}{2g} = \frac{A_c}{2b} = \frac{d_c}{2}$$



W		A		2/3 A		B		C		D		E		F		G		K	N	R		M		P		X	Y	Free-Flow Capacity (Second-Foot*)	
Ft	In.	Ft	In.	Ft	In.	Ft	In.	Ft	In.	Ft	In.	Ft	In.	Ft	In.	Ft	In.	In.	In.	Ft	In.	Ft	In.	Ft	In.	In.	In.	Minimum	Maximum
0	3	1	6-3/8	1	1/4	1	6	0	7	0	10-3/16	2	0	0	6	1	0	1	2-1/4	1	4	1	0	2	6-1/4	1	1-1/2	0.03	1.9
0	6	2	7/16	1	4-5/16	2	0	1	3-1/2	1	3-5/8	2	0	1	0	2	0	3	4-1/2	1	4	1	0	2	11-1/2	2	3	0.05	3.9
0	9	2	10-5/8	1	11-1/8	2	10	1	3	1	10-5/8	2	6	1	0	1	6	3	4-1/2	1	4	1	0	3	6-1/2	2	3	0.09	8.9
1	0	4	6	3	0	4	4-7/8	2	0	2	9-1/4	3	0	2	0	3	0	3	9	1	8	1	3	4	10-3/4	2	3	0.11	16.1
1	6	4	9	3	2	4	7-7/8	2	6	3	4-3/8	3	0	2	0	3	0	3	9	1	8	1	3	5	6	2	3	0.15	24.6
2	0	5	0	3	4	4	10-7/8	3	0	3	11-1/2	3	0	2	0	3	0	3	9	1	8	1	3	6	1	2	3	0.42	33.1
3	0	5	6	3	8	5	4-3/4	4	0	5	1-7/8	3	0	2	0	3	0	3	9	1	8	1	3	7	3-1/2	2	3	0.61	50.4
4	0	6	0	4	0	5	10-5/8	5	0	6	4-1/4	3	0	2	0	3	0	3	9	2	0	1	6	8	10-3/4	2	3	1.3	67.9
5	0	6	6	4	4	6	4-1/2	6	0	7	6-5/8	3	0	2	0	3	0	3	9	2	0	1	6	10	1-1/4	2	3	1.6	85.6
6	0	7	0	4	8	6	10-3/8	7	0	8	9	3	0	2	0	3	0	3	9	2	0	1	6	11	3-1/2	2	3	2.6	103.5
7	0	7	6	5	0	7	4-1/4	8	0	9	11-3/8	3	0	2	0	3	0	3	9	2	0	1	6	12	6	2	3	3.0	121.4
8	0	8	0	5	4	7	10-1/8	9	0	11	1-3/4	3	0	2	0	3	0	3	9	2	0	1	6	13	8-1/4	2	3	3.5	139.5

*Equals 1 cu ft per sec.

Legend:

W	Size of flume, in inches or feet.
A	Length of side wall of converging section.
2/3 *A*	Distance back from end of crest to gage point.
B	Axial length of converging section.
C	Width of downstream end of flume.
D	Width of upstream end of flume.
E	Depth of flume.
F	Length of throat.
G	Length of diverging section.
K	Difference in elevation between lower end of flume and crest.
N	Depth of depression in throat below crest.
R	Radius of curved wing wall.
M	Length of approach floor.
P	Width between ends of curved wing walls.
X	Horizontal distance to *H*, gage point from low point in throat.
Y	Vertical distance to *H*, gage point from low point in throat.

Source: *ORSANCO* (1952).

Figure 3.04. Dimensions and capacities of the Parshall measuring flume, for various widths.

where:

A_c = area at the critical depth, ft^2
d_c = critical depth, ft
V_c = critical velocity
b = width of flume

3.33 Flows in Partially Filled Pipes

Measurement of flows in partially filled pipes can be taken by several methods depending upon physical convenience. Where sections of pipe are exposed, a segment can be removed and substituted with a Parshall flume, weir box, or Palmer-Bowlus flume as previously discussed. If a straight nonconstricted run of pipe is exposed at both ends, flow estimates can be obtained by the depth-velocity method. For this purpose Table 3.04 lists cross-sectional areas of water at various depths for several pipe diameters. Calculation of flow is the same as for open channel flow measurement (Section 3.321).

3.34 Flows From Open-end Pipes

In most cases where pipes are used for in-plant transport of wastewater, the only practical point for flow measurement is at the discharge end of the system. Several methods and devices are suitable for use at this point.

3.341 CONTAINER AND STOPWATCH

If the flow to be measured can be readily captured in a container of practical dimensions, the container and stopwatch technique, discussed in Section 3.311, can be employed. To minimize observational errors, the container should be large enough to require at least 10 seconds to fill.

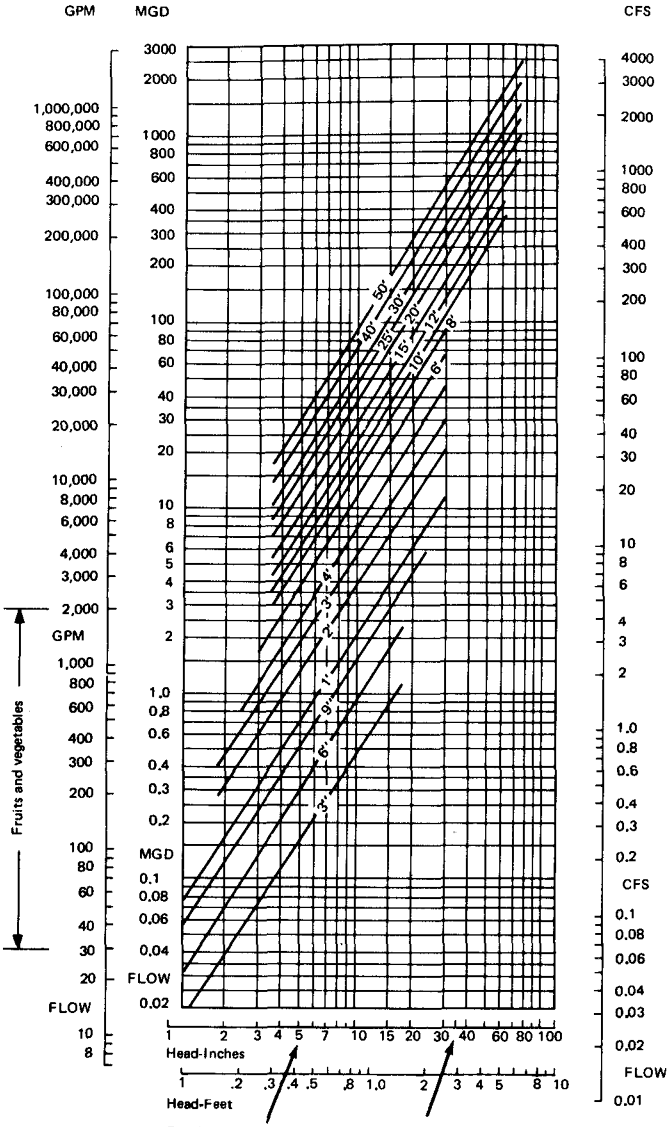
3.342 COORDINATE METHOD

This method can be used when the water discharges freely from the end of an open pipe. The calculation is derived from the physics principle of trajectory which relates the distance of a particle from a point to the velocity of that particle at the point of origin.

As illustrated in Figure 3.07 the position of the water after it has left the pipe is measured by the horizontal distance (X) and the vertical distance (Y) from the end of the pipe. Y must be a vertical distance and X must be parallel to the slope of the pipe.

With these measurements the flow can be calculated as follows:

$$Q = \frac{1880 \times A \times X}{Y}$$



5 inches is minimum full scale head with Foxboro float and cable meter

36 inches is maximum full scale head with Foxboro float and cable meter

Figure 3.05. Flow curves for Parshall flumes.

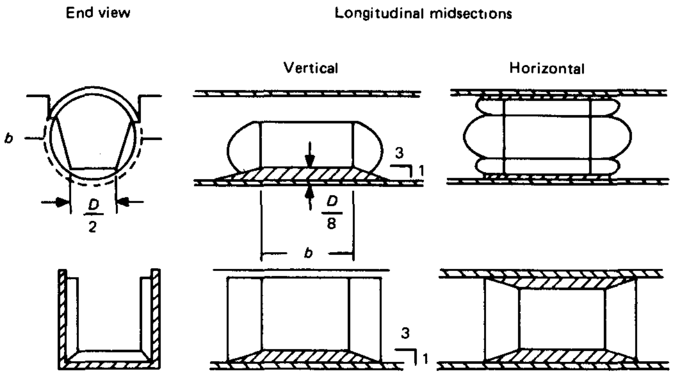


Figure 3.06. Various shapes of Palmer-Bowlus flumes.

TABLE 3.04
CROSS SECTIONAL AREA OF WATER IN PIPES AT VARIOUS DEPTHS OF FLOW

Depth of flow (d) inches	Cross sectional area — square feet (sq ft)				
	Diameter of pipe (D) — inches				
	6	8	10	12	15
2	.06	.07	.08	.09	.10
1/4	.07	.08	.09	.10	.12
1/2	.08	.09	.11	.12	.13
3/4	.09	.11	.12	.14	.15
3	.10	.12	.14	.15	.17
1/4	.11	.13	.15	.17	.20
1/2	.12	.15	.17	.19	.22
3/4	.13	.16	.19	.21	.24
4	.14	.17	.20	.23	.27
1/4	.15	.19	.22	.25	.29
1/2	.16	.20	.24	.27	.31
3/4	.17	.22	.26	.29	.33
5	.17	.23	.27	.31	.36
1/4	.18	.24	.29	.33	.38
1/2	.19	.26	.31	.35	.41
3/4	.19	.27	.32	.37	.43
6	.20	.28	.34	.39	.46
1/4		.29	.36	.41	.48
1/2		.30	.38	.43	.51
3/4		.31	.39	.45	.54
7		.32	.41	.48	.56
1/4		.33	.42	.50	.59
1/2		.34	.44	.52	.62
3/4		.35	.45	.54	.64
8		.35	.47	.56	.67
1/4			.48	.58	.69
1/2			.49	.59	.72
3/4			.51	.61	.74
9			.52	.63	.77
1/4			.53	.65	.79
1/2			.54	.67	.82
3/4			.54	.68	.84
10			.55	.70	.87
1/4				.71	.89
1/2				.73	.92
3/4				.74	.94

where

Q = flow in gallons per minute
A = cross sectional area of the fluid in the pipe in square feet
X = the distance in feet, measured parallel to the pipe, between the end of the pipe and the vertical gauge.
Y = the vertical distance in feet from the water surface at the end of the pipe to the intersection of the vertical gauge and the falling water surface.

To determine the cross sectional area, A:

1. Refer to the table for cylindrical pipes (Table 3.04).
2. For rectangular and other conduit configurations, refer to Section 3.321.

3.343 CALIFORNIA PIPE METHOD

This method was developed by Van Leer for determining the rate of flow from the open end of a partially filled pipe discharging freely into the air. It is especially suitable for measuring comparatively small flows in pipes but can be adapted to measure flows in open channels if the water can be diverted into a pipe without completely filling it.

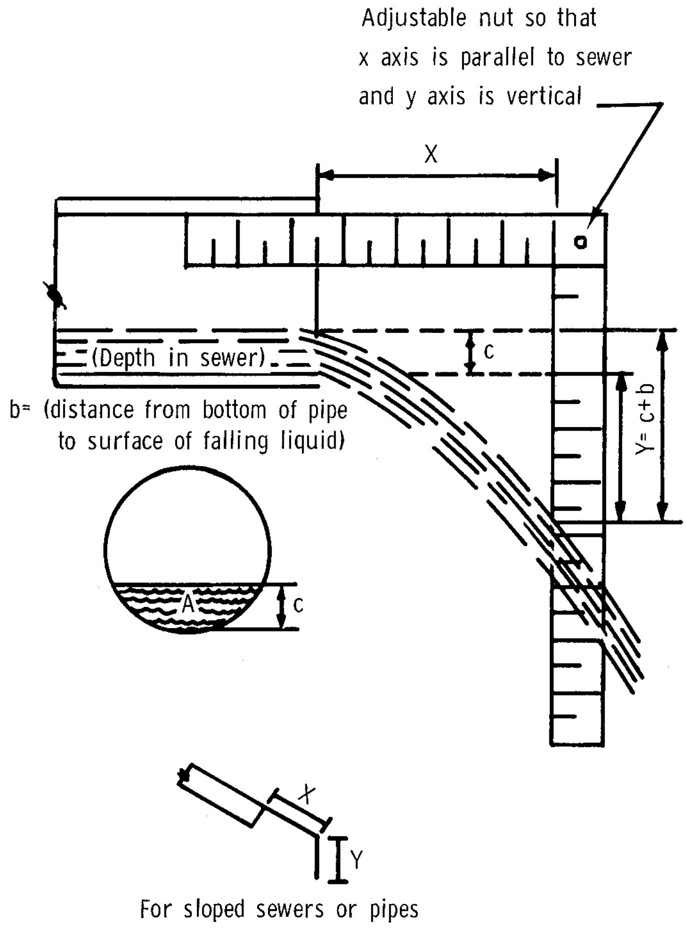


Figure 3.07. Measurement of x & y dimensions for open-pipe flow measurements.

An example of the California pipe method is illustrated in Figure 3.08. A nipple, N, of any convenient length, connects the lower supply line to the upper discharge pipe, M. A tee with an open top is used as an air vent to provide free circulation of air in the unfilled portion of the discharge pipe. The discharge pipe should be level and at least 6 diameters long.

Let "d" equal the internal diameter in inches of the discharge pipe and "a" equal the distance in inches from the top of the inside surface of the pipe to the water surface at the end of the discharge pipe. This distance can be measured approximately with a ruler or more accurately with calipers. The discharge in gallons per minute is given by the formula:

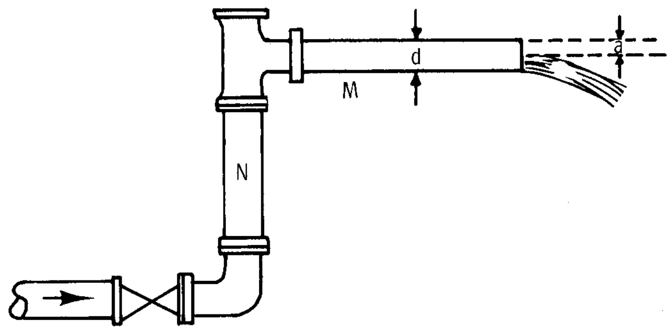


Figure 3.08. California pipe method.

$$Q = 449 \times c \times K$$

where

c is obtained by determining the value of a/d and finding the appropriate value for c in Table 3.05.

K is obtained from Table 3.06 for the diameter of the discharge pipe in use.

3.344 OPEN-FLOW MEASURING DEVICES

A variety of devices are available for measuring open-end discharges. These are constructed for attachment directly to the end of a pipe, and are designed and calibrated to enable direct visual observation of flows. Automatic recording instruments are available as accessories for many of these commercial models.

3.35 Pipes Under Pressure

A wide variety of flow meters, rate indicators and other devices for recording flows are used for systems in which fluids are under pressure. Due to the wide-spread use of these devices and the ready availability of specific information from their numerous manufacturers, the following section will be limited to a brief discussion of the more commonly used types of meters and their application to the food processing industry.

In-line flow meters can be classified into three categories based on the principle of operation. These basic categories are:

1. Propeller-type water meters
2. Differential producers
3. Magnetic flow meters

TABLE 3.05
VALUES OF "c"
FOR COMPUTING DISCHARGES BY CALIFORNIA PIPE METHOD

a/d	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	8.69	8.53	8.37	8.21	8.05	7.89	7.74	7.58	7.43	7.28
.1	7.13	6.98	6.83	6.69	6.54	6.40	6.28	6.12	5.98	5.85
.2	5.71	5.58	5.45	5.32	5.19	5.06	4.93	4.81	4.68	4.56
.3	4.44	4.33	4.21	4.09	3.98	3.87	3.76	3.65	3.54	3.43
.4	3.33	3.22	3.12	3.02	2.92	2.82	2.73	2.63	2.54	2.45
.5	2.361	2.273	2.186	2.102	1.018	1.937	1.857	1.778	1.701	1.626
.6	1.552	1.480	1.409	1.340	1.273	1.207	1.143	1.081	1.020	0.961
.7	0.904	0.848	0.794	0.741	0.690	0.641	0.594	0.548	0.504	0.462
.8	0.422	0.383	0.346	0.311	0.277	0.246	0.216	0.189	0.161	0.137
.9	.1146	.0940	.0753	.0586	.0438	.0311	.0205	.0119	.0056	.0015

TABLE 3.06
VALUES OF "K"
FOR VARIOUS PIPE DIAMETERS.
FOR CALIFORNIA PIPE METHOD.

d (in.)	K	d (in.)	K	d (in.)	K
3	.032	10	.636	18	2.73
4	.065	12	1.000	20	4.01
6	.179	14	1.467	24	5.58
8	.490	16	2.039	30	9.70
	d = 36"		K = 15.25		

3.351 PROPELLER-TYPE FLOW METERS

The propeller-type flow meter, schematically illustrated in Figure 3.09, is the most common type of meter used in measuring the flow of water in pressure systems. This meter consists essentially of a propeller, or a similar rotor, placed within a pipeline. The propeller turns in direct relation to the velocity of fluid flow in the pipe. By means of calibrated gears, the rotations are converted to volumes which are visually observable on the dial, or register, normally contained in the unit. Flow rates can be obtained by using a stopwatch while observing the meter dial.

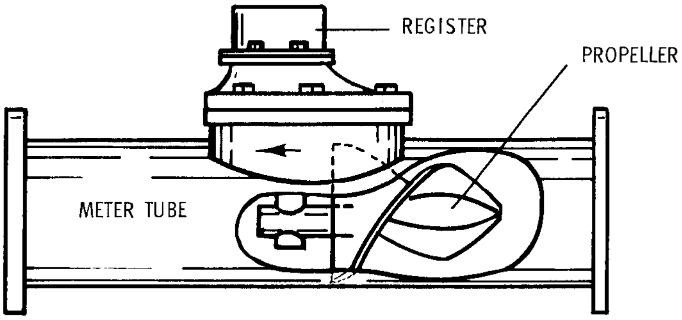


Figure 3.09. Propeller-type flow meter.

Accurate measurements with propeller-type meters require the maintenance of close tolerances between the propeller blades and the inside surface of the pipe or meter casing. This requirement precludes the use of these meters in pipelines carrying large solid material. However, these meters are excellent for measuring and recording the volume of water entering the plant and the volumes utilized by individual operations within the plant.

Although installation of water meters for a single survey would be prohibitively expensive, permanent installation of meters at strategic locations, especially at operations using large quantities of water, would provide means for keeping records of water usage. This is essential to the design and control of a water conservation program which, in turn, is invaluable for the development and operation of efficient and economical waste treatment and disposal systems.

3.352 DIFFERENTIAL PRODUCERS

These meters are in fairly common use and are available in a wide variety of forms. A typical meter is illustrated in Figure 3.10. Like the Parshall flume for open channels, these are based on the Venturi principle, relating pressure changes to the rate of flow in a pressurized pipe system. The pressure changes are created by a constriction in the inside diameter of the meter. Using a suitable gauge calibrated for each particular meter, the pressure change caused by this constriction is converted directly to flow rates. Accessory instruments are also available for any indicating, recording and totalizing combinations.

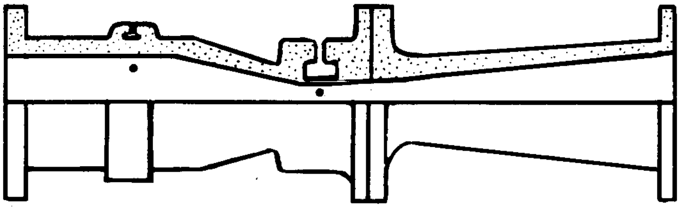


Figure 3.10. Hershel venturi tube (cut away view).

These instruments possess good accuracy. Since no moving parts are involved, they are essentially maintenance free. Use of these meters in the larger diameters is practical for flows containing solid particles since the diameter of the constriction can be selected sufficiently large enough to permit unimpeded passage of these particles through the meter. However, the problem which may preclude the use of differential-pressure meters for such streams is that of orifice clogging. Particles may clog the orifices leading to the pressure gauge, thereby rendering the meter inoperative. This type of meter, however, is well suited for measurement of flows in water lines.

3.353 MAGNETIC FLOW METERS

The electromagnetic flow meter is a relatively recent development in flow measuring devices. The operating principle of this meter is based upon Faraday's law of electromagnetic induction, which simply stated says:

> "The voltage induced across any conductor as it moves at right angles through a magnetic field is proportional to the velocity of that conductor."

Figure 3.11 illustrates how this principle has been applied to the flow meter. A uniform magnetic field is created around a section of pipe with electromagnets. As the fluid conductor (water) moves through the magnetic field surrounding the pipe, a voltage is generated at the electrodes. The magnitude of this induced voltage is measured by a suitable instrument and converted to measurements of flow.

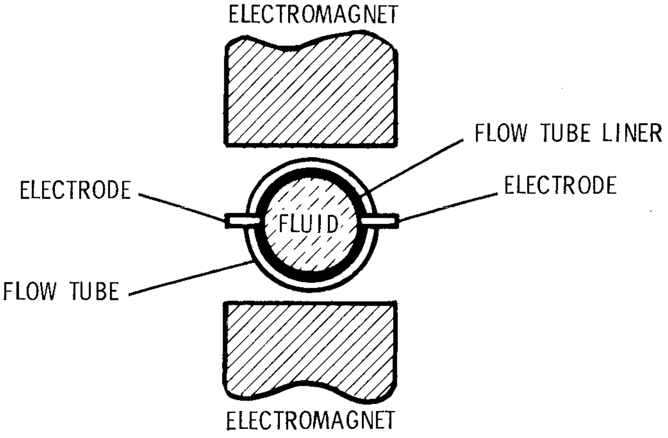


Figure 3.11 Operating principle of the electromagnetic flow meter (see text).

The operation of an electromagnetic flow meter is not affected by changes in liquid viscosity, density, line pressure, presence of solids, or turbulence of flow. Furthermore, the inside diameter of the pipe is free from constrictions or protuberances which might impede the flow of fluid in the pipe. Flows in water pipes, hydraulic conveying systems and waste pumping lines can all be monitored with such meters without concern for loss of head, solids build-up, clogging, or other problems associated with the other types of meters. These features render this meter extremely attractive for use in food processing plants.

3.4

METHODS FOR OBTAINING WASTEWATER SAMPLES

The type of information desired will dictate the method utilized for obtaining wastewater samples. Analysis of grab samples collected during the course of a day's operation will reveal temporal fluctuations in the physical and chemical characteristics of the waste, whereas the daily average values can be obtained with a minimum of analytical work from composite samples.

The type of sample, whether grab or composite, should also be selected on the basis of the stability of the constituent to be measured, and the degree of accuracy desired in the results. Below are listed some specific tests under the type of sample most suitable for its determination. However, most of these determinations can be made on either type of sample, and in a routine testing program this is frequently done.

Most Suitable Type of Sample for Various Determinations

Grab Sample	Composite Sample
pH	Biochemical oxygen demand
Total acidity	Chemical oxygen demand
Total alkalinity	Total solids
Chlorine residual	Suspended solids
Dissolved oxygen	Dissolved solids
Settleable solids	Ammonia nitrogen
	Orthophosphate phorphorus

It should be understood that a complete in-plant survey of wastewater sources would include both grab and composite samples and that these samples would be collected not only from the combined waste streams, but also at each piece of equipment which discharges liquid waste into the combined flow.

Regardless of the method used, the importance of representative sampling cannot be over-emphasized. Serious sampling errors will occur if the samples at each sampling site are not taken in the same manner each time. Since heavy particles will rapidly settle to the bottom of a container, errors in solids concentrations may occur when water samples are transferred from one container to another; the samples should be well-mixed whenever such transfers are made.

3.41 Grab Samples

Grab samples are small portions of material taken at random times from significant collection points. Grab samples should be taken at least twice daily – once in the morning and once in the afternoon of each day-shift operation. Hourly samples will yield a more complete profile of waste fluctuations occurring within the sampling period. Such fluctuations in the characteristics of grab samples are expected and reflect normal variations caused by changes in raw product volume and quality, style of pack, and other ingredient variations.

The equipment required for taking grab samples are:

1. A one-gallon capacity pail (plastic or stainless steel).
2. A large funnel.
3. A container-carrying rack.
4. Containers.
5. A simple dipper, fashioned from an enamel-lined can attached to a long pole, will facilitate obtaining samples from difficult-to-reach areas.

A very inexpensive and useful container for grab sample collection is a one-quart capacity, plastic-coated paper milk carton. These cartons can be used for storing samples in a frozen state with little danger of breakage due to ice expansion. Waste samples collected for determination of residual chlorine, hydrogen sulfide, dissolved oxygen, or phosphate content should be collected in wide-mouth screw cap glass jars with a closure assuring an air-tight fit. The jars should be completely filled with no air space remaining.

Procedure

One to four quarts of sample should be taken at each sampling, the amount depending upon the number of different determinations which are to be made. Care should be exercised to insure that the samples are free of large pieces of suspended material, such as sticks, stems or pieces of product which would be removed by the effluent screen.

When it is necessary to sample wastewater at different levels in a tank, a weighted bottle with a stopper in place may be lowered to the desired depth and the stopper removed by means of an attached string. The bottle is held in place until bubbles cease to rise. For routine sampling from large storage tanks, selection of the proper depth should be made with care; skimming the liquid surface should be avoided. A sampling point of one-third to one-half of the liquid depth is recommended.

The discharge from pipes and flumes should be sampled in such a manner that turbulence in the sampling device does not concentrate the heavier solids at the bottom while floating away suspended matter. This can be avoided by collecting the sample without overflowing the pail or dipper.

The containers should be clearly labeled by sampling point, date, and time of collection. Sampling points throughout the plant should be designated by a code, such as a letter to identify the product being packed and numbers to identify the sampling sites. A convenient way of labeling the milk carton containers is to write directly on the surface with a felt-tip marking pen containing permanent ink (available from Esterbrook Pen Company, Carters Ink Company, and others).

3.42 Composite Sampling Techniques

A composite sample consists of measured portions of wastewater collected at frequent regular intervals and combined into a single container. The sampling may cover any convenient time period, such as a shift or a 24-hour operation, with the individual portions collected at one-hour intervals.

Composite sampling has the disadvantage of not revealing fluctuations in waste concentrations which occur during the sampling period. However, it is a convenient method for determining average conditions in the waste flow over a period of time.

3.421 MANUAL METHOD

Equipment

The equipment required for manually composited samples is identical to that used for obtaining grab samples. Additionally, a large collection container with a capacity of 2 to 3 gallons should be provided.

Procedure

If the rate of waste discharge is fairly constant, a composite sample may be made up of individual samples of the same volume, each collected in the manner described for taking grab samples. If, however, the rate of discharge varies, as is usually the case, a weighted (proportional) sample is of greater value.

To obtain a proportional composite sample, the rate of waste flow must be known and the individual aliquots constituting the composite sample should be proportional in volume to the rate of waste flow at the time the sample is collected. For example, if the rate of flow at one sampling time is 500 gallons per minute (gpm) the sample at the time could be 50 ml or some multiple of that amount. If the rate of flow increases later to 1,000 gpm the sample at that hour would be 100 ml or some multiple of this amount. However, abnormal surges in the flow should be disregarded. The size of the individual portions should be such that the volume of the composite sample will be 2 to 3 gallons.

3.422 AUTOMATED APPARATUS

A wide variety of automatic sampling devices are commercially available. These devices collect and composite wastewater samples over a predetermined period, thereby releasing an individual from the responsibility of having to manually obtain periodic samples. Such samplers are available for almost all situations, whether samples are to be drawn from a sump or tank, a flume, or a pipe.

Current prices range from less than $200 for a simple device to over $3000 for a refrigerated proportional sampler. Selection of a suitable model will be determined by the requirements of each situation. Since there are many technical points that must be considered to avoid errors caused by inherent limitations of the various available models, the manufacturers should be consulted for recommendations. When selecting a sampling device, the following points should be considered:

1. Will the sampler obtain representative samples? Be certain there are no hoses or tubing which will contain a static volume of wastewater that will later be added to the composite sample.
2. Be certain that all valves and/or other orifices are of sufficient size to preclude clogging by particulate matter which might be present in the waste stream.
3. If the volume of liquid flowing in the waste stream varies frequently, does the sampler taken proportional samples? Or, can the sampler be readily adapted to do so?
4. Does the unit provide refrigerated storage for the composite? If not, will the sampler readily deliver aliquots of wastewater to a collecting container placed in a refrigerator? (See the following discussion, "Preserving Waste Samples.")
5. Is the construction of the sampler such that the device can be readily cleaned without tedious dismantling? Periodic cleaning is especially important for conduits, tubing and other parts which come in contact with the liquid waste.

3.43 Preserving Waste Samples

Most food processing wastes are relatively unstable because bacterial growth and chemical reactions can cause significant changes in a short time. For example, samples stored for one day at room temperature may be 10 to 40% lower in BOD than the fresh waste. The rate of change is influenced by temperature, pH of the sample, and the concentration of dissolved components. Any attempt to inhibit bacterial growth by the addition of bacteriostatic agents may hasten chemical changes or alter some physical characteristic of the waste. Chemical preservatives, such as chloroform, have been used to prevent bacterial growth, but these do not retard chemical and physical changes. Chemicals must not be added to waste samples reserved for BOD determinations.

Immediate analysis is the best insurance against significant errors in the use of grab samples. However, this is not always practical, especially when samples are collected from points quite distant from the laboratory. Furthermore, composite samples must often be stored for as long as 24 hours. To minimize compositional alterations in these samples, some means of preservation must be used.

3.431 PRESERVING SAMPLES IN THE FIELD

When collecting samples in the field, delays are often encountered before the samples can be delivered to the laboratory. Under such circumstances, the samples are often stored in ice. Insulated ice chests are convenient for this purpose, providing an inexpensive and portable means for assuring minimal changes in the waste. Collection containers are sealed, placed into the ice chests and packed with crushed ice. Samples can be held in such a manner for several hours in even the warmest climates. Storage duration can be prolonged by periodically draining the chest and repacking it with more ice. Care should be exercised to assure that water from the melting ice does not enter the containers, thereby diluting the waste samples.

3.432 REFRIGERATION

Refrigeration at a temperature of 34 to 40°F is the preferable and most common method for temporary preservation of waste samples, especially for storage of composite samples during the period of collection. Refrigeration retards bacterial growth, chemical reactions and physical changes. Samples can be stored in this manner up to 4 days.

3.433 FREEZING

In situations where delayed analysis of wastewater samples is necessary or desirable, the samples may be preserved by freezing. Flexible containers should be used and filled well below capacity so that damage will not result from ice expansion. Frozen samples can be stored for several months with minimal changes in chemical and physical characteristics.

3.434 THERMAL PROCESSING

An alternate method for prolonged storage of waste samples is preservations by thermal processing. Enamel-lined cans are filled with homogenous, or well mixed, samples. A headspace of 1/2 inch should be provided when the cans are closed. The cans are processed for 25 minutes at 240°F (or the equivalent) and water cooled. A felt-tip pen containing permanent ink can be conveniently used to label the cans after retorting.

3.5

LABORATORY PROCEDURES FOR ANALYSIS OF WATER AND WASTEWATER SAMPLES

This section is intended to serve as a convenient reference outlining the basic procedural steps to be followed in the routine analysis of water and wastewater samples. Complete discussion of each determination can be found in the references cited for each test. Laboratories routinely engaged in analytical work will find *Standard Methods for the Examination of Water and Wastewater* an invaluable reference. This book is published by the American Public Health Association (jointly with the American Water Works Association and the Water Pollution Control Federation), 1015 Eighteenth Street NW, Washington, DC 20036. Revised editions are released about every five years.

The determinations included in this section are those which are used most frequently in characterizing the chemical and physical properties of water and wastewater samples. Except for the initial discussion of pH measurement, the tests are listed in alphabetical order.

3.501 pH Determination

pH is a measure of the hydrogen ion concentration and, thus, the degree of acidity or alkalinity of the solution. The pH values are expressed by a numerical scale from 0 to 14, the mid-point, 7.0, being neutrality. The 0 to 7 range is the acid scale; 7 to 14, the alkaline scale. The pH of fruit and vegetable processing wastes may be expected to vary from 3.5 to 11.5, depending upon the product being packed and the type of operations conducted within the plant.

Accurate pH measurement of the plant effluent may be essential for successful treatment and disposal operations. Certain chemicals or chemical combinations are effective as flocculents only within a limited pH range. Biological treatment systems are also subject to optimum pH levels for efficient operation. Thus, liquid wastes being discharged to lagoons, to spray irrigation fields, to trickling filters, or to activated sludge systems may require pH adjustment.

THE ELECTROMETRIC METHOD.

The electrometric method is based on the assumption that hydrogen ions carry a positive electrical charge. By the introduction of suitable electrodes, the difference in charge (potential) between that of the solution and that of a standard cell can be determined by means of a potentiometer. The amount of this difference is a measure of the hydrogen ion concentration of the solution. Various types of electrodes and meters are available commercially for measuring pH and other ions (specific ion electrodes).

Procedure

Since each of the many pH meters now available varies somewhat in operation, step-wise procedures will not be given. The manufacturer's instructions must be followed for each instrument. Certain general steps, however, are applicable to all types of meters and electrodes.

1. Electrodes must be thoroughly wetted before use. Follow the manufacturer's instructions for preparation.
2. The pH meter must be standardized against a buffer solution, preferably one which has a pH close to that of the solution to be measured. The linearity of the instrument may be checked with the use of two buffer solutions of different pH.
3. The electrodes should be rinsed with distilled water and blotted with an absorbent tissue before and after immersion into a solution.
4. When the instrument is not in use, glass electrodes should be left immersed in distilled water and the meter placed in the "stand-by" or "off" position.

References

1. Bates, Roger G. *Determination of pH*, John Wiley and Sons, New York (1964).
2. National Canners Association, *Laboratory Manual for Food Canners and Processors*, Vol. 2, pp 168-177, The Avi Publishing Company, Inc., Westport, Conn. (1968).

3.502 Acidity

It is sometimes desirable to know the acidity of wastewater and whether the acidity is caused by mineral acids or weakly ionized acids. Titrating a sample to the methyl orange endpoint of pH 4.5 will determine "free acidity" which is caused by mineral acids. Titration to the phenolphthalein endpoint of pH 8.3 gives total acidity which will include both mineral and weak acids. More often it is required to know the amount of alkali needed to neutralize the acid in a given volume of wastewater.

3.5021 FREE AND TOTAL ACIDITY

Apparatus

1. Burette, 50 ml.
2. Erlenmeyer flasks, 250 ml, wide-mouth.
3. Assorted glassware – volumetric pipettes and flasks, graduated cylinders.
4. pH meter (optional).
5. Magnetic stirrer (optional).

Reagents

1. Sodium thiosulfate, 0.1N. Dissolve 25 g $Na_2S_2O_3 \cdot 5H_2O$ and dilute to 1 liter with distilled water.
2. Methyl orange indicator solution. Dissolve 0.5 g methyl orange in 1 liter distilled water.
3. Phenolphthalein indicator solution. Dissolve 5 g phenolphthalein in 500 ml 95% ethyl alcohol and add 500 ml distilled water. Add 0.02N NaOH drop-wise until a faint pink color appears.
4. CO_2-free distilled water. Use distilled water which has been freshly boiled for 15 minutes and cooled to room temperature.
5. Sodium hydroxide, 1N. Dissolve 40.0 g NaOH in 1 liter CO_2-free distilled water. Store in a pyrex glass bottle with a tight-fitting rubber stopper and protect from atmospheric CO_2 with a soda-lime tube.
6. Standard sodium hydroxide, 0.02N. Dilute 20.0 ml 1N NaOH to 1 liter with CO_2-free water. Standardize against potassium biphthalate as described in Section 3.522, Standardizing Analytical Reagents. Prepare this solution weekly and store in a rubber stoppered bottle protected with a soda-lime tube.

Procedure

Free Acidity. Place 50 ml of sample or an aliquot requiring less than 25 ml of titrant into an erlenmeyer flask. If free residual chlorine is present in the sample, add 0.05 ml (one drop) of 0.1N sodium thiosulfate solution. While gently swirling or stirring the sample, titrate with 0.02N NaOH to an endpoint of pH 4.5, or add 2 drops of methyl orange indicator and titrate until the color changes from pink to yellow. Note the volume of NaOH titrant used.

Total Acidity. Continue titrating with 0.02N NaOH to an electrometric endpoint of pH 8.3, or add 3 to 4 drops of phenolphthalein indicator and titrate until the first appearance of a permanent pink color.

Calculation

$$\text{Acidity as mg/l } CaCO_3 = \frac{A \times N \times 50{,}000}{B}$$

where

A = ml of standard sodium hydroxide
N = normality of NaOH titrant
B = ml of sample

For total acidity include the milliliters required to determine free acidity. Report the result as methyl orange or phenolphthalein acidity.

Reference

Standard Methods, (14th ed.), pp 460-465.

3.5022 DETERMINATION OF THE WEIGHT OF LIME REQUIRED TO BRING A GIVEN VOLUME OF WASTE TO A DESIRED pH

Procedure

Weigh to ±1 mg a small amount (2 to 3 g) of lime. Place the pH meter electrodes in a liter sample of the waste. Add lime slowly in small portions from the weighed sample. Stir the waste throughly between additions of lime. When the desired pH is reached, weigh the lime sample again and determine the difference from the original weight. The weight of the lime required to neutralize a known gallonage of wastewater can be calculated by the following formula.

Calculation

$$P = \frac{3.785 \times G \times W}{453.6}$$

where

P = pounds of lime needed
G = grams of lime used to neutralize 1 liter of waste
W = gallons of wastewater to be treated

Example

When 0.1 g of lime is required to raise the pH of 1 liter of waste to the desired pH level, how many pounds of lime are needed to treat 100,000 gallons of the waste?

$$\text{Pounds of lime} = \frac{3.785 \times 0.1 \times 100{,}000}{453.6} = 83.4 \text{ pounds}$$

3.503 Alkalinity

The alkalinity of natural water represents its content of carbonates, bicarbonates, and hydroxides. When products are being packed which require lye peeling, the dumping of the lye bath or the alkali carry-over from the bath may increase the hydroxide content of the waste to such an extent that a municipal sewage sewage disposal system might refuse to handle it. In such cases, the necessary amount of acid should be added to neutralize the alkali. Phenolphthalein alkalinity will indicate the presence of strong alkali, such as sodium hydroxide. Methyl orange or total alkalinity measures all forms of alkaline substances, including carbonates and bicarbonates.

3.5031 PHENOLPHTHALEIN AND TOTAL ALKALINITY

Apparatus

The apparatus listed under Acidity, Section 3.502, is also suitable for alkalinity determinations.

Reagents

Except for standard 0.02N sodium hydroxide, all reagents listed under Acidity, Section 3.502, are required. In addition, one of the following is necessary.

1. Standard sulfuric acid titrant, 0.02N. Prepare a stock solution approximately 0.1N by diluting 3.0 ml concentrated H_2SO_4 to 1 liter. Dilute 200 ml of the 0.1N stock solution to 1 liter with CO_2-free water.
2. Standard hydrochloric acid titrant, 0.02N. Prepare the 0.1N stock solution by diluting 9.5 ml concentrated HCl to 1 liter. Dilute 200 ml of the 0.1N stock solution to 1 liter with CO_2-free water.

Standardize either of the standard acid titrants against 0.0200N sodium carbonate, as described in Section 3.522, Standardizing Analytical Reagents.

Procedure

Phenolphthalein Alkalinity. Place 50 ml of sample or an aliquot requiring less than 25 ml of titrant into an erlenmeyer flask. If free residual chlorine is present in the sample, add 0.05 ml (one drop) of 0.1N sodium thiosulfate solution. While gently swirling or stirring the sample, titrate with 0.02N sulfuric or hydrochloric acid to an electrometric endpoint of pH 8.3, or add 3 drops of phenolphthalein and titrate to the disappearance of the pink color.

Total Alkalinity. Continue titrating the sample with 0.02N acid titrant to the electrometric endpoint of pH 4.5, or add 2 drops of methyl orange indicator and titrate until the indicator changes from yellow to pink.

Calculation

$$\text{Alkalinity as mg/l } CaCO_3 = \frac{A \times N \times 50{,}000}{B}$$

where

A = ml of standard acid titrant
N = normality of standard acid
B = ml of sample

For total alkalinity include the milliliters required to determine phenolphthalein alkalinity. When reporting results be certain to indicate which endpoint was used, i.e., phenolphthalein or methyl orange.

Reference

Standard Methods (14th ed.), pp 278-282.

3.5032 DETERMINATION OF AMOUNT OF COMMERCIAL SULFURIC ACID REQUIRED TO NEUTRALIZE A GIVEN VOLUME OF WASTEWATER

Procedure

Place a measured volume (500 ml or more) of wastewater in a beaker or a wide-mouth erlenmeyer flask. Insert the electrodes of a pH meter into the sample. While stirring, slowly add 0.02N sulfuric acid titrant until the desired pH level is reached. Calculate the volume of concnetrated commercial acid required to neutralize a known gallonage of wastewater by the following formula.

Calculation

$$V = \frac{0.02 \times A \times W}{B \times N}$$

where

V = gallons of concentrated acid required
A = ml of 0.02N acid titrant used
W = gallons of wastewater to be treated
B = ml of sample titrated
N = normality of the concentrated acid

Example

When 12 ml of 0.02N acid titrant are required to neutralize a 500 ml sample of wastewater, how many gallons of concentrated commercial sulfuric acid (36 N) are required to neutralize 100,000 gallons of this waste?

$$V = \frac{0.02 \times 12 \times 100{,}000}{500 \times 36} = 1.33 \text{ gallons of conc acid}$$

3.504 Calcium

Calcium is the fifth most abundant element found on earth. Its presence, with magnesium, contributes to the hardness of water. Calcium salts, in appreciable quantities, result in the formation of harmful scale in boilers, hot water lines, and cooking utensils. Reduction of calcium compounds in water supplies necessitates chemical softening treatment or ion-exchange techniques.

Apparatus

1. Burette, 50 ml.
2. Erlenmeyer flasks, 125 or 250 ml, preferably wide-mouth.
3. Assorted glassware – volumetric pipettes and flasks.

Reagents

(The reagents necessary for this test are commercially available, prepared and standardized for use as described.)

1. Sodium hydroxide, 1N. Dissolve 40.0 g NaOH and dilute to 1 liter with distilled water.
2. Murexide (ammonium purpurate) indicator. Prepare by dissolving 0.15 g of the dye in 100 g of absolute ethylene glycol. A dry form may be prepared by mixing 0.20 g murexide with 100 g solid NaCl and grinding to 40-50 mesh.

3. Standard EDTA titrant, 0.01M. Weight 3.723 g analytical reagent grade disodium ethylenediamine tetraacetate dihydrate (EDTA), $Na_2H_2C_{10}O_8N_2 \cdot 2H_2O$, in distilled water and dilute to 1 liter. Standardize against standard calcium solution as described in Section 3.521. Standard EDTA titrant which is exactly 0.0100M is equivalent to 0.4008 mg Ca per 1.00 ml.

Procedure

Use 50 ml of sample, or an aliquot diluted to 50 ml so that the calcium content is about 5 to 10 mg. If the alkalinity of the sample is higher than 300 mg/l $CaCO_3$, the endpoint may be improved by diluting an aliquot to 50 ml, or by neutralization with acid, boiling for one minute and cooling before proceeding. Add 2 ml sodium hydroxide solution, or a volume sufficient to produce a pH of 12 to 13. Stir and add 1 to 2 drops murexide solution, or 0.1 to 0.2 g of the indicator mixture. Add EDTA titrant slowly, with continuous stirring, to the endpoint as indicated by a color change of pink to purple. Check by adding 1 or 2 extra drops to assure no further color change occurs.

Calculations

$$\text{mg / 1 Ca} = \frac{A \times E \times 400.8}{B} \qquad (1)$$

$$\text{Calcium hardness as mg/l } CaCO_3 = \frac{A \times E \times 1{,}000}{B} \qquad (2)$$

where

A = ml of titrant (EDTA) used
B = ml of sample
E = mg $CaCO_3$ equivalent to 1.00 ml EDTA titrant at the calcium indicator endpoint (see Section 3.521).

Reference

Standard Methods (14th ed.), pp 185-191.

3.505 Chloride

The presence of chlorides, with sodium, is often responsible for salty tastes detected in water supplies. For this reason many regional water quality control agencies place limits on the permissible levels of chloride discharged in industrial effluents. This is of concern especially to olive, pickle and sauerkraut packers who use large quantities of salt as integral part of their operation. Chlorides in fresh water supplies are also of concern to others, since a high concentration exerts corrosive effects on pipes, tin-plated containers and other metallic objects and is detrimental to agricultural plants.

Selection of the appropriate method for analysis will be determined by the nature of the sample. The titrimetric method is most suitable for relatively low concentrations of chloride, such as found in potable water samples. The potentiometric method is recommended for wastewater samples from brining operations, for brackish and saline waters, and for wastewater samples where color interferes with detection of the indicator endpoint.

3.5051 TITRIMETRIC METHOD

Apparatus

1. Burette, 50 - 100 ml.
2. Assorted glassware.

Reagents

1. Chloride-free water. If necessary, any chloride impurities may be removed from distilled water by redistillation in an all-pyrex apparatus or by ion-exchange methods.
2. Potassium chromate indicator solution. Dissolve 50 g K_2CrO_4 in a small volume of water. Add a sufficient amount of silver nitrate solution to produce a definite red precipitate. Allow to stand for 12 hours, filter and dilute the filtrate to 1 liter with distilled water.
3. Standard silver nitrate titrant, 0.0141N. Dissolve 2.396 g $AgNO_3$ in 1 liter distilled water. Standardize against 0.0141N NaCl as described under Procedure. Store in a brown bottle, preferably protected from light. Silver nitrate solution which is exactly 0.0141N is equivalent to 0.500 mg chloride per 1.00 ml.
4. Standard sodium chloride solution, 0.0141 N. Dissolve 0.8241 g NaCl, previously dried at 140°C, in chloride-free water and dilute to 1,000 ml. Equivalence: 1.00 ml = 0.500 mg Cl.

Procedure

Use a 100 ml sample or an aliquot diluted to 100 ml. Adjust the pH of the sample to a pH range of 7 to 10, using a dilute solution of sulfuric acid or sodium hydroxide. Add 1.0 ml K_2CrO_4 indicator solution. Titrate with standard silver nitrate titrant to a pinkish-yellow endpoint. Establish a reagent blank value by titrating an aliquot of chloride-free water in the same manner.

Standardize the silver nitrate titrant by titrating exactly 10.0 ml standard sodium chloride solution following the procedure described above.

$$\text{Normality } AgNO_3 = \frac{0.141}{\text{ml } AgNO_3 \text{ used}}$$

Calculations

$$\text{mg/l Cl} = \frac{(A-B) \times N \times 35{,}450}{C} \qquad (1)$$

where

A = ml titrant used for sample
B = ml titrant used for blank
C = ml sample
N = normality of $AgNO_3$

$$\text{mg/l NaCl} = \text{mg/l Cl} \times 1.65 \qquad (2)$$

3.5052 POTENTIOMETRIC METHOD

Apparatus

1. Burette, 50 ml.
2. Potentiometer, or pH meter equipped with a millivolt scale.
3. Glass and silver-silver chloride electrodes.
4. Mechanical stirrer with plastic- or glass-coated stirring bar.
5. Assorted glassware – beakers, pipettes.

Reagents

1. Standard sodium chloride solution, 0.0141N. Prepare as described under Titrimetric Method.

2. Nitric acid, concentrated.
3. Standard silver nitrate titrant, 0.0141N. Prepare and standardize as described under Titrimetric Method.

Procedure

Establish the potentiometric endpoint for the instrument by developing a differential titration curve as described in the following. (As in the case of pH meters, potentiometric instruments vary in operating detail. The manufacturer's instructions should be followed for preparation, adjustment and operation of each instrument. The following procedural steps apply for all instruments.)

Deliver 10.0 ml standard sodium chloride solution into a 250-ml beaker and dilute to about 100 ml. Add 2.0 ml concentrated HNO_3. Immerse the stirring bar and electrodes in the solution. Start the stirrer. Set the instrument to the appropriate scale and begin incremental additions of the standard silver nitrate titrant. Wait until the meter reading becomes stable before adding subsequent increments. Initially, large increments of $AgNO_3$ will produce small changes in the meter reading. As the endpoint is approached smaller and equal increments (0.1 or 0.2 ml) should be added at longer intervals so that the exact endpoint can be determined. Record the millivolt reading at each point and note the volume of $AgNO_3$ used up to that point. Obtain a differential titration curve by plotting the millivolt reading (mv) against the volume (ml) of $AgNO_3$ used. The procedure is illustrated in Figure 3.12. The millivolt reading corresponding to the point of inflection in the curve is the endpoint which can be used for all subsequent determinations.

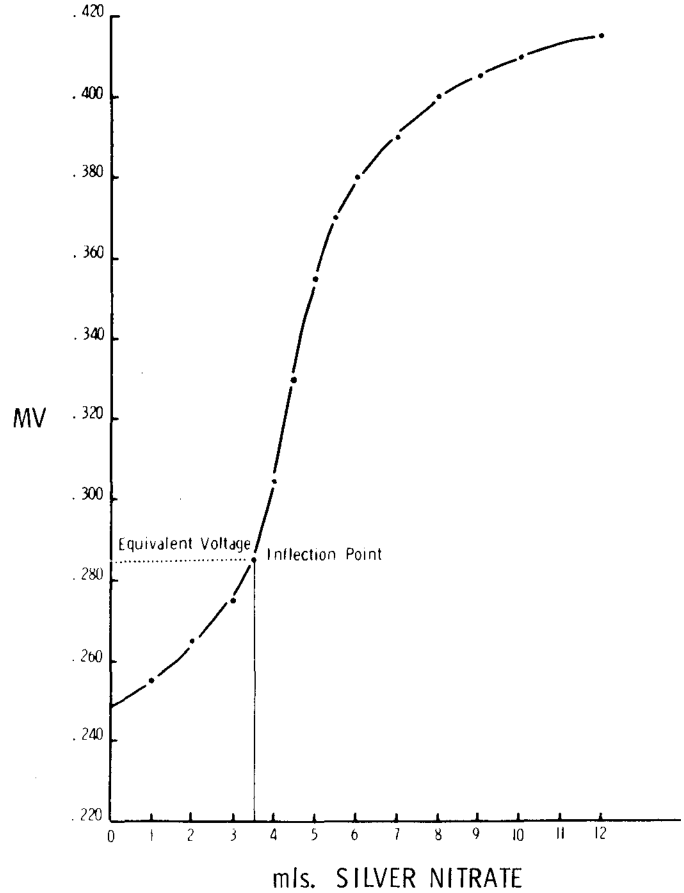


Figure 3.12. Chloride titration curve.

Deliver exactly 100.0 ml of sample, or an aliquot containing not more than 10 mg chloride, into a 250-ml beaker. Add concentrated HNO_3 dropwise until acidic to litmus paper then add 2.0 ml in excess. Cool and dilute to 100 ml, if necessary. Immerse the stirrer and electrodes in the solution and start the stirrer. Add standard $AgNO_3$ until the predetermined endpoint is reached. Repeat, using a chloride-free water blank.

Calculation

Use equations as stated under Titrimetric Method.

References

1. *Standard Methods* (14th ed.), pp 302-309.
2. NCA, *Laboratory Manual,* Vol. 2, pp 291-292.

3.506 Hardness

Calcium and magnesium salts are major contributors to the degree of hardness of water. Scale deposits in boilers and hot water lines are caused by insoluble salts formed when hard water is heated to boiling. Boiler compounds contain chelating agents which tie up calcium and magnesium ions, thereby preventing the formation of scale. Ion-exchange techniques are also used to "soften" water.

Apparatus

1. Burette, 25 ml.
2. Porcelain casseroles or evaporating dishes.
3. Assorted glassware.

Reagents

(The reagents required for this test as listed below are commercially prepared for immediate use.)

1. Buffer solution. Dissolve 16.9 g ammonium chloride, NH_4Cl, in 143 ml concentrated ammonium hydroxide, NH_4OH. Add 1.25 g EDTA (magnesium salt) and dilute to 250 ml with distilled water. Store in tightly stoppered plastic container. Prepare this solution monthly.
2. Indicator. Mix 0.5 g of the dye Eriochrome Black T with 4.5 g hydroxylamine hydrochloride. Dissolve the mixture in 100 ml 95% ethyl alcohol. A dry form of indicator may be prepared by mixing 0.5 g of the dye with 100 g NaCl. The dye is commercially available as "Eriochrome Black T" (Geigy), "Pontachrome Black TA" (du Pont), and "Solochrome Black WDFA" (C. I. E.).
3. Standard EDTA titrant, 0.01M. Prepare and standardize as described under Calcium, Section 3.504.

Procedure

Dilute 25.0 ml of sample, or an aliquot requiring less than 15 ml EDTA titrant, to about 50 ml with distilled water in a porcelain casserole or evaporating dish. Add 1 to 2 ml of buffer solution, followed by 1 to 2 drops of indicator solution or 0.1 to 0.2 g dry-powder mixture. Add the standard EDTA titrant slowly while continuously stirring the solution, until the last reddish tint disappears. The color of the solution, viewed preferably in daylight or daylight fluorescent lamp, is blue when the endpoint has been reached. The titration time should not exceed 5 minutes.

Calculation

$$\text{EDTA hardness as mg/l CaCO}_3 = \frac{A \times E \times 1{,}000}{B}$$

where

A = ml EDTA titrant used
B = ml sample
E = mg $CaCO_3$ equivalent to 1.00 ml EDTA titrant (see Section 3.521)

Reference

Standard Methods (14th ed.), pp 200-206.

3.507 Magnesium

Magnesium is measured with calcium during the EDTA hardness determination, Section 3.506. The magnesium concentration in a water sample can be estimated by determining both calcium and EDTA hardness and applying the following formula:

$$\text{mg/l Mg} = \frac{\text{EDTA hardness (mg/l CaCO}_3\text{)}-\text{Ca hardness (mg/l)}}{4.116}$$

3.508 Nitrogen, Ammonia

Nitrogen is generally essential for microbiological activity. Since ammonia nitrogen is the form most readily utilized by microorganisms, biological waste treatment systems are often supplied with ammonia compounds during the treatment of nitrogen-deficient industrial wastes. Analysis should be performed on fresh samples.

Apparatus

1. Distillation apparatus – an 800-ml kjeldahl flask with a suitable condensor connected by a kjeldahl bulb.
2. Erlenmeyer flasks, 250 ml.
3. Burette, 25 or 50 ml.

Reagents

1. Phosphate buffer solution, 0.5M. Dissolve 14.3 g anhydrous KH_2PO_4 (potassium phosphate, monobasic) and 68.8 g anhydrous K_2HPO_4 (potassium phosphate, dibasic) in distilled water and dilute to 1 liter.
2. Standard sulfuric acid titrant, 0.02N. Prepare a stock solution approximately 0.1N by diluting 3.0 ml concentrated H_2SO_4 to 1 liter. Dilute 200 ml of the 0.1N stock solution to 1 liter. Standardize against 0.020N sodium carbonate, as described in Section 3.522. Other strengths of standard acid may be used.
3. Mixed indicator. Mix 2 volumes of 0.2% methyl red (dissolved in 95% ethyl alcohol) with 1 volume of 0.2% methylene blue (also in 95% ethyl alcohol). Prepare this mixture fresh every 30 days.
4. Indicating boric acid solution. Dissolve 20 g H_3BO_4 in water, add 10 ml mixed indicator and dilute to 1 liter with distilled water. Prepare fresh every 30 days.
5. Zinc metal. Coarse granular, reagent grade.

Procedure

Clean the distillation apparatus by redistilling a small volume of distilled water. Neutralize a 100 to 400 ml volume of sample to pH 7 and place in an 800-ml kjeldahl flask. Add 25 ml phosphate buffer solution. If the sample contains an excess of 250 ml phosphate buffer solution. If the sample contains an excess of 250 mg/l calcium, initially add up to 40 ml buffer solution and adjust pH to 7.4. Dilute the sample to about 400 ml, add a few granules of zinc metal, and distill. Collect about 150 ml of distillate in an erlenmeyer flask containing 50 ml indicating boric acid solution. Assure collection of all the ammonia by keeping the tip of the condensor well below the level of the boric acid solution. The temperature in the condensor should not rise above 29°C. Back titrate with the standard H_2SO_4 solution until a pale lavender color is attained. Run a concurrent reagent blank using distilled water in place of the sample.

Calculation

$$\text{mg/l ammonia N} = \frac{(A - B) \times N \times 14{,}000}{C}$$

where

A = ml H_2SO_4 used in sample
B = ml H_2SO_4 used in blank
N = normality of H_2SO_4
C = ml sample

Reference

Standard Methods (14th ed.), pp 407-418.

3.509 Nitrogen, Organic

Nitrogen determinations are made on food products primarily as a measure of protein content. In water analysis, the organic nitrogen content is related to pollution by sewage or industrial wastes. For biological waste treatment systems the nitrogen content of the wastewater is used as an index for determining the amount of nutrients which must be added to the system for efficient operation.

Organic nitrogen may be determined by using the residue from the ammonia nitrogen determination (Section 3.508) in place of the sample for total nitrogen (Section 3.510); or by determining ammonia and total nitrogen independently, the difference representing organic nitrogen.

3.510 Nitrogen, Total

Total kjeldahl nitrogen measures ammonia and organic nitrogen, but does not include nitrite and nitrate nitrogen. Total kjeldahl nitrogen may be performed satisfactorily on solid material by substituting an appropriate weight of sample in place of the volume of liquid prescribed. The procedural steps remain the same.

Apparatus

In addition to the apparatus listed under Ammonia Nitrogen, Section 3.508, the following are required:

Digestion apparatus. A rack supporting kjeldahl flasks heated by gas or electric burners should be provided. The necks of the flasks should extend into a corrosion resistant pipe connected to an efficient exhaust system (a mechanical blower or water aspirator may be used to carry away fumes).

Reagents

In addition to the reagents listed under Ammonia Nitrogen, the following are required:

1. Digestion reagents (available in pre-weighed packets from chemical supply houses).
   a. Potassium sulfate, K_2SO_4, reagent grade.
   b. Mercuric sulfate solution. Dissolve 8 g red mercuric oxide, HgO, in 50 ml 1+5 H_2SO_4 (one part conc H_2SO_4 + 5 parts distilled water) and dilute to 100 ml with distilled water.
2. Sulfuric acid, concentrated.
3. Sodium hydroxide-sodium thiosulfate solution. Dissolve 500 g NaOH and 25 g $Na_2S_2O_3 \cdot 5H_2O$ and dilute with distilled water to 1 liter.
4. Phenolphthalein indicator solution. Dissolve 5 g phenolphthalein in 500 ml 95% ethyl alcohol and add 500 ml distilled water. Add 0.02N NaOH dropwise until a faint pink color appears.

Procedure

Place 300 ml of sample, or an aliquot diluted to 300 ml, into an 800-ml kjeldahl flask. Add 30 ml conc H_2SO_4 and one packet of digestion reagent, or 6.7 g K_2SO_4 and 1.5 ml $HgSO_4$ solution. Add a few boiling stones or glass beads to prevent bumping. Place on digestion rack and heat mixture gently until frothing ceases, then boil briskly for 20 to 30 minutes after the solution has become clear. Cool the flask and add 300 ml distilled water. Make the solution alkaline with the hydroxide-thiosulfate solution, using phenolphthalein as an indicator. Immediately connect the flask to the distilling apparatus and then mix by swirling. Distill, collecting the distillate as described under Ammonia Nitrogen, Section 3.508. Titrate with 0.02N H_2SO_4. Run a reagent blank concurrently with the sample.

Calculation.

$$\text{mg/l total kjeldahl nitrogen} = \frac{(A - B) \times N \times 14{,}000}{C}$$

where

A = ml H_2SO_4 used for sample
B = ml H_2SO_4 used for blank
N = normality of H_2SO_4
C = ml sample

Reference

Standard Methods (14th ed.), pp 437-440.

3.511 Oil and Grease

Unlike most analytical procedures whereby the concentration of specific chemical entities are determined, the procedure for oil and grease measures the quantity of a number of substances. These substances share one common physical characteristic – their solubility in freon or other suitable organic solvent. Hence, the procedure may include biological lipids, mineral hydrocarbons, and numerous other materials.

Samples for oil and grease determinations should be collected in separate glass containers, such as wide-mouth jars. Each sample should be reserved for a separate determination and not be subdivided after collection. When analysis must be delayed, the sample should be preserved with 1 ml conc H_2SO_4 per 80 g sample.

Apparatus and Supplies

1. Separatory funnels with teflon stopcocks.
2. Distilling flask, 125 ml.
3. Water bath.
4. Filter paper, Whatman No. 40, 11 cm.

Reagents

1. Hydrochloric acid, HCl, 1+1.
2. Freon (1, 1, 2-trichloro-1, 2, 2-trifluoroethane), boiling point 47°C. The solvent should leave no measurable residue upon evaporation; distill if necessary.
3. Sodium sulfate, Na_2SO_4, anhydrous crystals.

Procedure

Collect about 1 liter of sample. Acidify to pH 2 or lower with 1+1 HCl (generally about 5 ml is sufficient). Transfer the acidified sample to a separatory funnel. Thoroughly rinse the sample jar with 30 ml freon and add this washing to the separatory funnel. Shake vigorously for 2 min. Allow the layers to separate. Drain the freon layer through a funnel containing solvent-moistened filter paper into a clean, tared distilling flask. If a clear solvent layer cannot be obtained, place 1 g or more Na_2SO_4 on the filter paper and drain the emulsified solvent onto the crystals. Extract twice more with 30 ml freon after first rinsing the sample jar with each solvent aliquot. Combine the extracts in the tared distilling flask and wash the filter paper with an additional 10 to 20 ml freon. Distill the freon from the flask in a water bath at 70°C. Place the flask on a warm steam bath for 15 min and draw air through the flask for 1 min by applying vacuum. Cool in a dessicator for exactly 30 min and weigh.

Note: Hexane or petroleum ether may be substituted in place of freon for routine monitoring other than for results to be reported.

Calculation

$$\text{mg/l oil and grease} = \frac{(A - B) \times 1{,}000}{\text{ml sample}}$$

where A = net weight of residue from extraction
B = residue from freon blank

Reference

Standard Methods (14th ed.), pp 515-516.

3.512 Oxygen (Dissolved Oxygen)

An adequate supply of dissolved oxygen is required in water sustaining fish and other aquatic organisms. Unstable waste, when discharged into receiving waters, will rapidly deplete the dissolved oxygen content in the receiving water. Thus, dissolved oxygen determinations are used extensively to determine the degree of septicity of a body of water. The efficiency of biological treatment systems, especially those with mechanical aeration components, is often measured in terms of the dissolved oxygen content of the system effluent.

Apparatus

1. Sample bottles, preferably glass stoppered of the type used

for BOD determinations.
2. Burette, 25 ml.
3. Assorted glassware – pipettes, graduated cylinder.

Reagents

1. Manganese sulfate solution. Dissolve 480 g $MnSO_4 \cdot 4H_2O$, 400 g $MnSO_4 \cdot 2H_2O$, or 364 g $MnSO_4 \cdot H_2O$ in distilled water, filter and make up to 1 liter. If there is doubt about the water of crystallization, adjust the specific gravity to 1.270 at 20°C to give a solution of equivalent strength.
2. Alkaline-Iodide-Azide solution. Dissolve 700 g potassium hydroxide, 150 g potassium iodide, and 10 g sodium azide, separately in small portions of distilled water. Combine the solutions of KOH and KI, and dilute to 950 ml. Cool the solution to room temperature and slowly add the sodium azide solution (10 g in 40 ml water) with constant stirring to avoid localized heating. Make up to 1 liter. (500 g NaOH may be substituted for KOH; 135 g of NaI for KI).
3. Sulfuric acid, concentrated.
4. Starch indicator solution. To 5 g of starch (soluble, arrowroot or potato) in a mortar, add a little cold water and grind to a thin paste. Pour into 1 liter of boiling distilled water. Stir and allow to settle overnight. Use the clear supernatant liquor which can be preserved by the addition of 1.25 g salicylic acid or 4 g zinc chloride per liter.
5. Sodium thiosulfate stock solution, 0.1N. Dissolve 24.84 g $Na_2\text{-}S_2O_3 \cdot 5H_2O$ in 1 liter freshly boiled and cooled distilled water. Add 5 ml of chloroform per liter as a preservative.
6. Standard sodium thiosulfate titrant, 0.025N. Dilute 250.0 ml $Na_2\text{-}S_2O_3$ stock solution to 1,000 ml with freshly boiled and cooled distilled water. Standardize against 0.025N potassium bi-iodate or potassium dichromate as described in Section 3.522.

Procedure

Collect wastewater samples in glass stoppered sample bottles in such a manner that air bubbles are not mixed with the sample, and the bottles are filled completely so that no air space remains. Analyze the samples as soon as possible.

To each 300 ml BOD bottle, add well below the surface of the liquid 2 ml of $MnSO_4$ solution, followed by 2 ml of the alkaline-iodide-azide solution. Insert the stopper without trapping air bubbles and discard the excess liquid. Distribute the precipitate by inverting the bottle several times (agitation should last no longer than 40 to 50 seconds). Allow the precipitate to settle until one-third of the liquid in the bottle appears clear. Add 2 ml conc H_2SO_4 down the neck of the bottle, re-stopper the bottle and agitate by inverting several times or until the precipitate has completely dissolved. The concentration of iodine, and hence the intensity of the brown color, will depend on the concentration of oxygen present in the sample.

Measure 203 ml of the sample into an erlenmeyer flask (3 ml is allowed for sample lost by displacement with the reagents). Titrate with 0.025N $Na_2S_2O_3$ until the iodine is reduced to a pale straw color. Add 1 or 2 ml of starch solution and titrate to the first disappearance of the blue color. Disregard a return of the color after standing. Record the number of ml $Na_2S_2O_3$ used. If the normality of the sodium thiosulfate solution is exactly 0.025N and the volume of sample titrated is compensated for displacement by the reagents, the ml of $Na_2S_2O_3$ used will be equal to the milligrams per liter dissolved oxygen present in the sample. Otherwise use the following formula.

Calculation

$$\text{mg/l DO} = \frac{A \times N \times 8{,}000}{B}$$

where

A = ml $Na_2S_2O_3$ used
N = normality of $Na_2S_2O_3$
B = ml sample

Reference

NCA Laboratory Manual, Vol. 2, pp 346-348.

3.513 Oxygen Demand, Biochemical (BOD)

For many years, investigators have attempted to measure the strength of wastewater containing dissolved organic compounds in terms of their effect upon streams or other bodies of water into which the wastes are discharged. The standard method for measuring this effect is the biochemical oxygen demand (BOD) test which determines the amount of oxygen, in parts per million (ppm), required during stabilization by microbial activity of a known amount of decomposable organic matter.

The test is based on an apparent direct relationship between the pollutional strength of the organic waste and the amount of oxygen that will be required in the biochemical reactions, catalyzed by microbial enzymes, to convert dissolved materials to carbon dioxide, water and inorganic nitrogen compounds. Actually, the test measures a series of complex interrelationships leading to the final products in the stabilized waste. The oxygen demand value is a measure of the relationship between the oxygen demand and the rate of increase in microbial activity, the rate of microbial activity being proportional to the concentration of nutrients in the organic waste. Thus, a completely stabilized waste is not capable of causing oxygen depletion in surface waters.

THE 5-DAY B.O.D. TEST

The BOD test was developed to simulate in the laboratory the conditions and activities taking place in water receiving organic wastes. Complete stabilization of organic matter would require more than 100 days at 20°C, but such a long period is impractical for ordinary investigations. Instead, samples of the wastes are diluted, if this is necessary, and incubated for 5 days at 20°C. For cannery wastes high in carbohydrates, this gives a particularly useful BOD value, since it represents most of the oxygen necessary to stabilize the carbonaceous and readily oxidized materials. The 5-day BOD value has been estimated to represent approximately 68 percent of the total BOD.

Because of the many factors measured in the BOD test, sources of error are numerous. However, when the conditions of the stest are properly controlled, and the procedure rigidly standardized, the BOD test becomes a useful tool in waste disposal studies.

Apparatus

Dilution water preparation.

1. Large container, such as a 5-gallon carboy, equipped with aeration and siphon tubes.
2. Aerator – laboratory air line or electric air pump.
3. Assorted glassware – graduated cylinders, pipettes.

Bottle-dilution method.

1. BOD bottles, 300-ml with water seal.
2. Assorted glassware – volumetric flasks and pipettes.
3. Plastic or paper cups, 1 oz. (Dixie or Lily cups or equivalent).

Cylinder-dilution method. In addition to the apparatus above:

1. Graduated cylinder, 1 liter.
2. Mixing rod, plunger type.
3. Aspirator pump attached to the cold water faucet.
4. Siphon tube. Fashion this from 2 pieces of pyrex tubing connected by rubber or plastic tubing.

Incubation. One of the following is required:

1. BOD incubator – recommended. (Complete incubators or compact temperature control units to convert any ordinary refrigerator to an incubator are available from scientific equipment suppliers.)
2. A room in which the temperature will not vary more than 2F° above or below 68°F.
3. Water bath controlled at 68 ± 2°F.

Reagents

Dilution water.

1. Ferric chloride solution. Dissolve 0.25 g $FeCl_3 \cdot 6H_2O$ in distilled water and dilute to 1 liter.
2. Calcium chloride solution. Dissolve 27.5 g anhydrous $CaCl_2$ in 1 liter distilled water.
3. Magnesium sulfate solution. Dissolve 22.5 g $MgSO_4 \cdot 7H_2O$ in 1 liter distilled water.
4. Phosphate buffer solution. Dissolve 34 g monobasic potassium phosphate (KH_2PO_4) in 500 ml distilled water. Add approximately 175 ml of 1N NaOH or until pH 7.2 is reached. Then add 1.5 g ammonium sulfate, $(NH_4)_2SO_4$, and dilute to 1 liter.
5. Bacterial seed solution. Obtain the effluent from the primary clarifier at the local sewage treatment plant. Allow the liquor to stand for 30 to 60 minutes, then decant the supernatant. Aliquots of this solution may be dispensed into small plastic bags and preserved in a freezer.

Pretreatment of samples.

1. Sulfuric acid solution, 1N. Cautiously add 30 ml conc H_2SO_4 to 500 ml distilled water. Dilute to 1 liter.
2. Sodium hydroxide solution, 1 N. Dissolve 40 g NaOH in distilled water and dilute to 1 liter.
3. Sodium thiosulfate solution, 0.1N. Prepare as described in Section 3.512.

Determination of dissolved oxygen.

All reagents required for the Dissolved Oxygen determination, Section 3.512, are also required for measuring Biochemical Oxygen Demand.

Procedure

Preparation of dilution water. The standard dilution water is prepared by the addition of certain chemicals to distilled water. Unless the results of the BOD studies are to be compared to results obtained by other laboratories using standard dilution water, any clean water free of organic matter or inhibitory substances will be satisfactory. If the water is known to contain inorganic salts and is well buffered, add 2 ml of the bacterial seed solution to each liter of dilution water. Fairly soft water may be benefited by the addition of 1.25 ml per liter of phosphate buffer solution prior to addition of the bacterial seed solution.

If distilled water is used, add 1 ml each of the ferric chloride, calcium chloride and magnesium sulfate solution, 1.25 ml of the phosphate buffer solution and 2 ml of the bacterial seed solution to each liter of dilution water.

Before use, the dilution water should be aerated by bubbling air through it until it is saturated (overnight or at least 6 hours). The amount of oxygen which dissolves will depend on ambient temperature and barometric pressure. Results of dissolved oxygen determinations can be checked against the oxygen solubilities given in Table 3.07.

Pretreatment of samples. Since it is necessary for microorganisms to live and multiply in the sample, it is advisable to remove or neutralize any substances present in inhibitory concentrations.

Samples of waste that are acid or alkaline should be neutralized to pH 7 ± 0.5. Samples which are to be highly diluted may not require preliminary neutralization. Chlorinated wastes must be dechlorinated with sodium thiosulfate solution. Because the addition of starch as an indicator would add more organic matter, the dechlorination can best be carried out either by determining the amount of chlorine present in a trial sample, and then calculating the amount of sodium thiosulfate solution needed to neutralize it; or by making additions of sodium thiosulfate solution to trial samples, containing starch indicator, to establish the amount necessary to be added to the test samples. Waste samples which require high dilution for the BOD test may have the inhibitory substances diluted beyond the point where their toxic effects are appreciable.

Preparation of samples. It is usually necessary to make a fairly high dilution of raw food processing wastes. Several dilutions of the same sample should be made until experimentation has shown which is the most suitable. The fol-

TABLE 3.07

SOLUBILITY OF OXYGEN IN FRESH WATER EXPOSED TO STANDARD CONDITIONS*

Temperature		Dissolved oxygen	Temperature		Dissolved oxygen
°C	°F	in ppm by weight	°C	°F	in ppm by weight
10	50	11.33	32	89.6	7.60
12	53.6	10.83	34	93.2	7.40
14	57.2	10.37	36	96.8	7.20
16	60.8	9.95	38	100.4	7.00
18	64.4	9.54	40	104	6.80
20	68	9.17	42	107.6	6.60
22	71.6	8.83	44	111.2	6.40
24	75.2	8.53	46	114.8	6.20
26	78.8	8.22	48	118.4	5.80
28	82.4	7.92	50	122	5.60
30	86	7.63			

*Adapted from "Standard Methods for the Examination of Water and Wastewater", values calculated by G. C. Whipple and M. C. Whipple from measurements of C. J. J. Fox. Based on an atmosphere containing 20.9% oxygen under a pressure of 760mm of mercury.

lowing dilutions of the waste are suggested: 1 to 50, 1 to 100, 1 to 200, 1 to 500.

Two methods are available for making the dilutions. In the cylinder method, a 1 liter graduated cylinder is siphoned half-full of dilution water without entrapment of air. The appropriate quantity of carefully mixed waste sample is added and the cylinder filled to the liter mark with dilution water. The dilution is mixed with a plunger type mixing rod, with care to avoid the entrapment of air. The dilution is then siphoned into BOD bottles, which are filled to overflowing. This allows the stoppers to be inserted without leaving an air bubble. The delivery tube should extend beneath the surface of the water at all times. The 1000 ml diluted sample is sufficient in volume for duplicate bottles.

A simpler technique is available for range finding trials when a high degree of accuracy is not essential or where a wide range of dilutions may be necessary. This consists of adding the appropriate amounts of waste sample directly to the BOD bottles by means of calibrated pipettes. The bottles are then filled with just sufficient dilution water to allow insertion of the stoppers without overflowing the bottles and without leaving an air bubble under the stoppers. If the strength of the waste indicates samples too small to pipette accurately, dilutions may be made of the sample before measuring. However, this technique is best when there is no prior dilution.

With either of the above methods, blanks are prepared. These are simply bottles filled with only the dilution water. The diluted samples and the blanks are incubated for 5 days at 20°C (68°F).

Incubation of samples. Since microbial activity is temperature dependent, it is important that incubation be carried out at the prescribed temperature. The bottles should be in the dark to prevent algae growth and the water seal around the stopper must be maintained to prevent oxygen assimilation from the atmosphere. Loss of water can be minimized by inverting a plastic or paper cup over the stopper and neck of the BOD bottles.

Determination of dissolved oxygen. At the end of the incubation period, the dissolved oxygen content in each of the bottles is measured. Follow the procedure described in Section 3.512, Dissolved Oxygen.

The incubated dilutions should show a lower oxygen content than that found in the blanks. The amount of this difference should be roughly proportional to the difference in concentration of organic matter added to each dilution. However, there may be wide variations in results from different dilutions of the same sample. This cannot always be explained on the basis of error in technique, but is largely due to variables which cannot be controlled. It is recommended that the results obtained from dilutions showing a 40 to 70 percent oxygen depletion be selected as the most reliable.

Calculations

Knowing the dissolved oxygen values in mg/l (ppm), the BOD value may be calculated by means of the following formulae:

1. For the cylinder-dilution method.

$$\text{mg/l BOD} = (\text{DOB} - \text{DOD}) \times \text{DF} \qquad (1)$$

where

DOB = mg/l DO in the dilution water blank.
DOD = mg/l DO in the diluted sample.
DF = dilution factor (the number of times 1 ml of the sample was diluted).

2. For the bottle-dilution method.

$$\text{mg/l BOD} = \frac{100}{P} \times (\text{DOB} - \text{DOD}) \qquad (2)$$

where

$$P = \frac{\text{ml of sample added to bottle} \times 100}{\text{capacity of bottle in ml}}$$

DOB = mg/l DP in incubated blank.
DOD = mg/l DO in diluted sample.

References

1. NCA, *Laboratory Manual,* Vol. 2, pp 348-352.
2. *Standard Methods* (14th ed.), pp 543-550.

Examples

Figures 3.13 and 3.14 illustrate sample data sheets which contain the information which should be recorded by the analyst for each BOD determination.

Type of waste: CLING PEACH WASTE
Source of sample: GRAB SAMPLE FROM DISCHARGE TO SEWER

Date	Time	Sample Number	Bottle Number	Amt. of Sample	Dilution Factor	Dissolved Oxygen	D. O. Reduction	5-day BOD
				(ml/l)		(mg/l)	(mg/l)	
8-1	10:00 AM	4	85	BLANK	–	9.2	–	
			87	BLANK	–	9.2	–	
			90	10	100	1.2	8.0	–
			92	4	250	3.8	5.4	1350
			98	2	500	6.4	2.8	–

Figure 3.13. Sample record sheet — BOD by cylinder dilution method.

Type of waste: SPINACH CANNING
Source of sample: 24-HOUR COMPOSITE FROM COMBINED DISCHARGE

Date	Time	Sample Number	Bottle Number	Bottle Capacity	Amt. of Sample	Conc. of Sample	D. O.	D. O. Reduction	5-day BOD
				(ml)	(ml)	(%)	(mg/l)	(mg/l)	
5-10	4:00 PM	6	8	302.0	BLANK	–	9.2	–	–
			12	301.8	BLANK	–	9.2	–	–
			15	303.2	5	1.65	6.0	3.2	–
			17	298.8	10	3.35	3.5	5.7	170
			18	[illegible]	15	4.99	1.8	7.4	–

Figure 3.14. Sample record sheet — BOD by bottle dilution method.

3.514 Oxygen Demand, Chemical (COD)

For many years the standard method for measuring the pollutional strength of wastewaters has been the biochemical oxygen demand (BOD) test, which determines the amount of dissolved oxygen, in milligrams per liter (mg/l), required during stabilization of decomposable organic matter by aerobic biochemical action. However, results from the BOD test are subject to variations from numerous sources, and therefore, reproducibility of results is poor. Furthermore, the BOD test results are not known until 5 days after the samples have been collected.

In recent years many investigators have attempted to substitute other methods which would overcome these major disadvantages. Chemical oxygen demand (COD) methods have offered most encouragement in this respect. Simply described, these tests measure the amount of oxygen consumed from a chemical oxidant, such as potassium dichromate. The tests are carried out under conditions which can be exactly reproduced and the results are obtained quickly.

In considering the use of COD methods for measuring the strength of cannery wastes, it must be understood that the BOD and COD tests involve separate and distinct reactions. Chemical oxidation measures carbon and hydrogen, but not nitrogen, in organic materials. Furthermore, the COD tests do not differentiate between biologically stable and unstable compounds. For example cellulose is measured by chemical oxidation, but is not measured biochemically under the aerobic processes usually found in streams. Despite these differences, a number of investigators have found a reliable and useful relationship between BOD and COD values for certain types of wastes.

Relationship of COD and BOD for Fresh Cannery Wastewaters

In laboratory and field studies wastewaters from a number of fruit canning operations were used in evaluating the usefulness of chemical oxygen demand values. Table 3.08 gives the results of a series of tests in which values for total solids, COD and BOD are compared for three fruit wastes. In these studies the average 5-day BOD values for the fresh wastes were found to be between 70 - 72% of the COD values. Of more significance was the close correlation between the COD and the 20-day BOD values.

The relationship between COD and BOD values found in these studies may not be the same for all types of food processing wastes. Wastewaters from the processing of corn, peas, asparagus, and other vegetables differ from fruit wastes in their organic composition. However, the work of other investigators has indicated that with these wastes, also, a useful correlation can be determined between the two methods.

It is recommended that, whenever possible, the COD method be used as a routine control measure, but only after initial correlations with BOD values have been determined for each type of wastewater. This would eliminate the necessity of determining BOD values for all waste samples. COD results may then also be used to obtain proper dilution factors for BOD determinations. However, use of the COD method should not be made dependent on the establishment of a correlation factor.

3.5141 STANDARD METHOD

This method is currently the only universally accepted method for determining the chemical oxygen demand of sewage and industrial wastes. Its major advantage is its applicability to a wide variety of chemical compounds.

Apparatus

1. Reflux apparatus – a 250-ml erlenmeyer flask and a 300 mm condenser connected by a ground-glass joint.
2. Hot plate with sufficient power to insure boiling of the reflux mixture.
3. Burette, 50 ml.
4. Assorted glassware – volumetric pipettes and flasks.

Reagents

1. Standard potassium dichromate solution, 0.250N. Dry a quantity of $K_2Cr_2O_7$ (primary standard grade) at 103°C for 2 hours; cool to room temperature in a dessicator. Weigh 12.259 g, dissolve in distilled water and dilute to 1,000 ml.

TABLE 3.08

RELATIONSHIP OF COD TO 5-DAY AND 20-DAY BOD FOR FRUIT CANNING WASTES

Type of Waste	Total Solids	COD	5-day BOD	20-day BOD	BOD_5/COD	BOD_{20}/COD
	(ppm)	(ppm)	(ppm)	(ppm)		
Apricot	2425	2460	1700	2200	0.691	0.894
	2075	1514	1100	1408	0.727	0.930
	4143	3220	2200	3400	0.683	1.056
	2170	1820	1300	1900	0.714	1.044
	2565	2180	1500	2100	0.688	0.963
	9888	9540	6500	9490	0.681	0.995
Ave. Value:	3878	3456	2383	3401	0.697	0.980
Peach	2449	1907	1310	2020	0.687	1.059
	1747	1235	930	1280	0.753	1.036
	866	620	450	575	0.726	0.927
	1918	1440	1000	1225	0.694	0.781
	3890	2820	2000	2750	0.709	0.975
	3430	2580	1930	2450	0.748	0.950
Ave. Value:	2383	1767	1270	1717	0.720	0.955
Apple	706	428	300	433	0.701	1.012
	782	474	375	488	0.791	1.030
	5098	3801	2570	3745	0.676	0.985
	9742	7563	5700	7500	0.754	0.992
	13042	10132	6740	10240	0.665	1.011
Ave. Value:	5874	4480	3137	4477	0.717	1.006

2. Sulfuric acid reagent. Add 22 g silver sulfate, Ag_2SO_4 (reagent powder), to a 9-lb bottle of concentrated H_2SO_4. Allow 1 to 2 days for the Ag_2SO_4 to dissolve. Label this bottle "For COD use".
3. Standard ferrous ammonium sulfate titrant, 0.25N. Dissolve 98 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in distilled water. Add 20 ml conc H_2SO_4, cool and dilute to 1,000 ml. Standardize this solution daily against the standard potassium dichromate solution as described below.
4. Ferroin indicator solution. Combine 1.485 g 1, 10-phenanthroline monohydrate and 0.695 g $FeSO_4 \cdot 7H_2O$, dissolve with distilled water and dilute to 100 ml.
5. Mercuric sulfate, reagent grade crystals.

Procedure

Standardize the ferrous ammonium sulfate titrant in the following manner. Dilute 10.0 ml standard potassium dichromate solution to about 100 ml. Add 30 ml conc H_2SO_4 and cool. Add 2 or 3 drops ferroin indicator solution and titrate with ferrous ammonium sulfate until a color change from blue-green to reddish brown is observed. Calculate the actual normality of the titrant by the following formula:

$$\text{Normality} = \frac{\text{ml } K_2Cr_2O_7 \text{ x } 0.25}{\text{ml Fe } (NH_4)_2(SO_4)_2}$$

Place 0.4 g $HgSO_4$ in the refluxing flask. Add 20.0 ml of sample or an aliquot diluted to 20.0 ml with distilled water. Mix thoroughly. Add 10.0 ml standard potassium dichromate solution. While swirling the flask, carefully add 30 ml sulfuric acid reagent (containing Ag_2SO_4). Place several glass beads into the mixture to prevent bumping. Attach the flask to the condensor and heat the mixture under reflux for 2 hours. This period can be shortened if trials indicate maximum COD values are achieved within a shorter time.

Cool the reflux system and wash down the condensor with distilled water. Dilute the mixture to about 100 ml and cool to room temperature. Add 2 or 3 drops ferroin indicator solution and titrate the excess dichromate with standard ferrous ammonium sulfate titrant. Disregard any reappearance of the blue-green color.

A blank containing the reagents and 20 ml distilled water in place of the sample should be refluxed and titrated as described.

Calculation

$$\text{mg/l COD} = \frac{(B - A) \text{ x N x } 8{,}000}{C}$$

where

A = ml titrant used for sample
B = ml titrant used for blank
N = normality of titrant
C = ml sample

Note: A standard solution of either glucose or potassium acid phthalate may be used to evaluate technique and the quality of the reagents.

Reference

Standard Methods (14th ed.), pp 550-554.

3.5142 "RAPID" METHOD

A recent development which appears promising is the "rapid" COD procedure discussed in this section. It also is applicable to a wide variety of samples and has the added advantage of being much less time-consuming. Oxidizability of most compounds, particularly the carbohydrates, compares favorably to the Standard Method.

Apparatus

1. Erlenmeyer flasks, 500 ml.
2. Assorted glassware – volumetric pipettes, graduated cylinder.
3. Hot plate.
4. Thermometer, partial immersion.
5. Burette, 50 ml.

Reagents

1. Standard potassium dichromate solution, 0.05N. Dissolve 2.4518 g $K_2Cr_2O_7$ (primary standard grade, dried at 103°C) in distilled water and dilute to 1,000 ml.
2. Dichromate oxidizing solution. Dissolve 5 g $K_2Cr_2O_7$ and 20 g $AgSO_4$ in a solution containing 1 liter conc H_2SO_4 and 1 liter conc (85%) H_3PO_4.
3. Standard ferrous ammonium sulfate titrant, 0.05N. Dissolve 20 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in distilled water. Add 20 ml conc H_2SO_4, cool and dilute to 1 liter. Standardize this solution daily against standard potassium dichromate solution as described below.
4. Ferroin indicator solution. Combine 1.485 g 1, 10-phenanthroline monohydrate and 0.695 g $FeSO_4 \cdot 7H_2O$, dissolve with distilled water and dilute to 100 ml.
5. Mercuric sulfate, reagent grade crystals.

Procedure

Pipette 10.0 ml standard potassium dichromate solution into a 250-ml erlenmeyer flask and dilute to about 100 ml with distilled. Add 30 ml conc H_2SO_4 and cool. Add 2 or 3 drops ferroin indicator solution and titrate with ferrous ammonium sulfate until a color change from blue-green to reddish brown is observed. Calculate the actual normality of the titrant by the following formula:

$$\text{Normality} = \frac{\text{ml } K_2Cr_2O_7 \text{ x } 0.05}{\text{ml } Fe(NH_4)_2(SO_4)_2}$$

Place approximately 0.3 g $HgSO_4$ into a 500 ml erlenmeyer flask. Pipette 5.0 ml sample, or a 5.0 ml aliquot of previously diluted sample, into the flask and mix to dissolve the $HgSO_4$. Carefully add 25.0 ml dichromate oxidizing solution to the flask and mix by swirling. Place the flask on a preheated hot plate and heat the solution to 165 ± 1°C, swirling the flask and checking the temperature frequently.

When the desired temperature is reached (about 5 minutes) remove the flask from the hot plate and cool. Cautiously add 300 ml distilled water by pouring the water down the neck of the tilted flask (beware of splattering acid). Cool the solution in a water bath to room temperature. Add 5 drops ferroin indicator and titrate with ferrous ammonium sulfate titrant to the endpoint indicated by a sharp change in color from blue-green to reddish-brown. Blanks should be run concurrently by substituting 5.0 ml distilled water for the sample.

Calculation

$$\text{mg/l COD} = \frac{(B - A) \times N \times 8{,}000}{C}$$

where

A = ml titrant used for sample
B = ml titrant used for blank
N = normality of titrant
C = ml sample

Reference

Jeris, John S., "A Rapid COD Test", *Water and Waste Engineering, 4*:89-91 (May, 1967).

3.515 Phosphate

Phosphates contained in wastewaters tend to promote the development of algae (eutrophication) in receiving waters. This has created aesthetically unacceptable conditions in many lakes and streams. The major sources of phosphates have been from agricultural runoff, sewage (due largely to phosphate-containing household detergents), and some industrial wastes. However, phosphorus is essential for microbial activity. Therefore, phosphates are utilized extensively as chemical additives to biological treatment systems for phosphorus-deficient wastes. The problem of eutrophication necessitates close control over the chemical dosages applied to such systems.

3.5151 ORTHOPHOSPHATE – ASCORBIC ACID METHOD

Apparatus

1. Electrophotometer (Bausch and Lomb "Spectronic 20" or equivalent) capable of measuring at 880 mμ (infrared phototube required). A light path of at least 0.5 cm is satisfactory.
2. Acid-washed glassware. To eliminate possible phosphate contamination from commercial detergents, all glassware should be cleaned with hot dilute HCl and rinsed with distilled water.

Reagents

1. Phenolphthalein indicator solution. Dissolve 5 g phenolphthalein in 500 ml 95% ethyl alcohol and add 500 ml distilled water. Then add 0.02N NaOH dropwise until a faint pink color appears.
2. Sulfuric acid solution, 5N. Cautiously add 70 ml conc H_2SO_4 to distilled water and dilute to 500 ml.
3. Potassium antimonyl tartrate solution. Dissolve 1.3715 g $K(SbO)C_4H_4O_6 \cdot 1/2\, H_2O$ in 400 ml distilled water in a 500-ml volumetric flask and dilute to volume. Store in a glass stoppered bottle.
4. Ammonium molybdate solution. Dissolve 20 g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 500 ml distilled water. Store in a plastic bottle at 4°C.
5. Ascorbic acid, 0.1M. Dissolve 1.76 g ascorbic acid in 100 ml distilled water. Store at 4°C; solution is stable for about 1 week.
6. Combined reagent. Mix the following proportions of the above reagents in the listed sequence to prepare 100 ml of the combined reagent: 50 ml 5N sulfuric acid solution, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution, and 30 ml ascorbic acid solution. Mix after the addition of each reagent. All reagents must be at room temperature prior to addition. If turbidity forms in the combined reagent after the addition of any solution, shake the mixture and let it stand until the turbidith disappears before processing. The combined reagent is stable for 4 hours.
7. Stock phosphate solution. Dissolve 219.5 mg anhydrous potassium phosphate, monobasic, KH_2PO_4, in distilled water and dilute to 1,000 ml. Equivalence: 1.00 ml = 50.0 μg PO_4-P.
8. Standard phosphate solutions. Dilute 50.0 ml stock phosphate solution to 1,000 ml with distilled water. Equivalence: 1.00 ml = 2.50 μg P.

Procedure

Pipet 50.0 ml sample into a clean, dry 125-ml erlenmeyer flask. Add 1 drop phenolphthalein indicator. If a red color develops add 5N sulfuric acid solution dropwise until the color just disappears. Add 8.0 ml combined reagent and mix thoroughly. After at least 10 min but no longer than 30 min, measure the color absorbance of each sample at 880 mμ, using a reagent blank as the reference solution.

If the samples are highly colored or turbid, prepare a blank by adding all the reagents except ascorbic acid and potassium antimonyl tartrate to the samples. Subtract the absorbance of the sample blanks from the absorbance of the respective unknown samples.

Obtain the weight (mg) of orthophosphate (as P) in the sample from a phosphate standard curve. This curve can be obtained by plotting on semi-log paper the absorbance readings from a suitable number of phosphate standards which have been treated in the manner described above. The plot should be a straight line passing through the origin.

Calculation

$$\text{mg/l } PO_4 \text{ (as P)} = \frac{\text{mg P} \times 1{,}000}{\text{ml sample}}$$

Reference

Standard Methods (14th ed.), pp 466-468, 481-482.

3.5152 TOTAL PHOSPHATE

To measure the total phosphate content of water, all forms of phosphate must be hydrolyzed to orthophosphate and determined by the preceding method.

Apparatus

1. Hot plate or autoclave.
2. Glass scoop. To hold approximately 0.4 g ammonium persulfate.

Reagents

1. Phenolphthalein indicator solution.
2. Strong-acid solution. Cautiously add 300 ml conc H_2SO_4 to 600 ml distilled water. Cool and dilute to 1,000 ml with distilled water.
3. Ammonium persulfate, solid.
4. Sodium hydroxide, NaOH, IN.

Procedure

To 50 ml of well mixed sample or an aliquot diluted to 50 ml, add 1 drop phenolphthalein indicator. Discharge the red color, if it develops, by dropwise additions of the strong-acid solution. Add a 1 ml excess strong-acid solution and 0.4 g ammonium persulfate. Boil the sample gently for 30-40 min or until a final volume of 10 ml is reached (or autoclave for 30 min at 15-20 psig). Cool, add 1 drop phenolphthalein indicator and neutralize to a faint pink color with IN NaOH solution (40 g NaOH in 1 liter distilled water). Dilute the sample to 100 ml with distilled water.

Determine the orthophosphate content by the Ascorbic Acid Method, Section 3.5151. Report as Total P.

Reference

Standard Methods (14th ed.), p 476.

3.516 Potassium and Sodium

Potassium and sodium salts are used extensively in brining operations. These ions, with chloride, are primarily responsible for salty tastes detected in water supplies. Sodium ions are also responsible for diminishing permeability of soils, thereby exerting detrimental effects on lands used for agricultural and land disposal purposes. For these reasons potassium and sodium contamination must be closely monitored.

FLAME PHOTOMETRIC METHOD

The flame photometric method is the most rapid and reliable analytical method for potassium and sodium determinations. The two are closely related, emitting wavelengths upon combustion which tend to enhance each other. Therefore, the two are discussed together in this section.

Apparatus

1. Flame photometer (Beckman Model DU Spectrophotometer with appropriate accessories, or the equivalent).
2. Acid-washed glassware. Errors due to contamination can be minimized by washing all glassware with a nitric acid solution (1 part HNO_3 + 9 parts H_2O) and rinsing several times with deionized distilled water.
3. Polyethylene bottles for storage of reagents and samples.

Reagents

1. Deionized distilled water. Prepare by passing distilled water through a mixed bed of ion-exchange resins (strongly basic anion-exchanger in the hydroxyl form and strongly acidic cation-exchanger in the hydrogen form). Use this water for all reagent preparation, sample dilution, and calibration.
2. Stock potassium solution. Dry reagent grade KCl at 110°C and cool to room temperature. Dissolve 1.907 g KCl and dilute to 1,000 ml with deionized distilled water. 1.00 ml = 1.00 mg K.
3. Intermediate potassium solution. Dilute 10.0 ml stock potassium solution to 100 ml with deionized distilled water. 1.00 ml = 0.100 mg/K. Use this solution to prepare the standard curve in the 1-10 mg/l range.
4. Standard potassium solution. Dilute 10.0 ml intermediate potassium solution to 100.0 ml with deionized water. 1.00 ml = 10.0 μg K. Use this solution to prepare the 0.1-1.0 mg/l curve.
5. Stock sodium solution. Dry reagent grade NaCl at 140°C and cool to room temperature. Dissolve 2.542 g NaCl and dilute to 1,000 ml with deionized distilled water. 1.00 ml = 1.00 mg Na.
6. Intermediate sodium solution. Dilute 10.0 ml stock sodium solution to 100.0 ml with deionized water. 1.00 ml = 0.100 mg Na. Use this solution to prepare the 1-10 mg/l Na calibration curve.
7. Standard sodium solution. Dilute 10.0 ml intermediate sodium solution to 100.0 ml. 1.00 ml = 10.0 μg Na. Use this to prepare the 0.1-1.0 mg/l Na curve.

Procedure

The differences which exist among the models of flame photometers precludes formulation of detailed procedures applicable to each instrument. Instructions issued by the manufacturer of the instrument should be coupled with personal investigations to determine the most suitable procedure for preparation of the samples, optimum operating conditions at the desired concentration level, and effects of interfering substances and means of minimizing these effects.

The photometer should be located away from direct sunlight and protected from drafts, dust and tobacco smoke. Contaminations may also arise from manual handling, corks, filter papers, soap and cleaning mixtures.

Sodium. Establish a calibration curve using a series of standard solutions in the ranges 0-1.0, 0-10.0, or 0-100 mg/l Na. Measure the emission of each solution at 589 mμ. Repeat several times to obtain a reliable average reading for each solution. Measure the emission of the samples (diluted to the proper concentration if necessary) in the same manner and determine the sodium concentration by referring to the calibration curve. For increased accuracy, obtain an estimate of the potassium content in the wastewater sample and add an appropriate quantity of potassium to each of the sodium standard solutions. Use these solutions to obtain a corrected calibration curve.

Potassium. Establish a calibration curve in the same manner described for sodium. Measure the emissions at 768 mμ. For increased accuracy, obtain an estimate of the sodium content in the samples and add an appropriate quantity of standard sodium solution to each of the potassium standard solutions.

Calculation

mg/1 Na or K = (mg/l in aliquot) x D

where

$$D = \text{dilution ratio} = \frac{\text{ml sample} + \text{ml distilled water}}{\text{ml sample}}$$

Reference

Standard Methods (14th ed.), pp 234-235, 250-253.

3.517 Settleable Solids

Information of the amount of settleable solids in food processing wastes provides a basis on which to predict the sludge load in settling basins, clarifiers, stream beds or sewer lines. The method described is semi-quantitative and useful only for estimation of the volume of sludge which can be anticipated.

Apparatus

1. Imhoff cones (Corning No. 2160 or 2180, or equivalent).
2. Supporting rack or ring stand.
3. Stirring rod.
4. Interval timer (optional).

Procedure

Fill an Imhoff cone to the liter mark with a thoroughly mixed sample. Allow to settle for 45 minutes. At the end of this time gently stir the contents of the cone to re-suspend the solids clinging to the walls. Allow the solids to settle for an additional 15 minutes, record and report as milliliters per liter settleable solids.

Reference

Standard Methods (14th ed.), pp 95-96.

3.518 Solids – Total

The total solids determination measures all matter which is contained in a water or wastewater sample. Included in the determination are suspended materials, which contribute to the turbidity of water, and dissolved components, such as sugars and salts, which contribute to tastes (objectionable or otherwise) detected in water supplies. Despite the fact that some volatile organic compounds may be excluded in the analysis, which is conducted at the boiling point of water, the total solids is a useful tool for the qualitative determination of the pollutants contained in wastewater samples.

Total solids, which is the residue remaining after evaporation of water from a sample, can be subdivided into fixed and volatile fractions. The fixed solids, determined by combustion of the total solids sample, represents the inorganic contaminants contained in the waste sample; the volatile solids represents the organic matter. The procedural steps are graphically depicted in Figure 3.15.

3.5181 TOTAL SOLIDS DETERMINATION

Apparatus

1. Steam table.
2. Evaporating dishes. Select one of the following:
   a. Platinum or silica – suitable for samples to be combusted.
   b. Porcelain – acceptable for combustion; etched by alkali.
   c. Glass – unacceptable for combustion; suitable for total solids by evaporation.

Procedure

Obtain the tare weight of a clean evaporating dish by placing it in a drying oven for 1 hour at 103°C, cooling for 45 minutes in a dessicator and weighing. Place 50-100 ml well-mixed wastewater sample into the evaporating dish. Evaporate the sample to dryness by leaving the dish on a steam table. Drying time is dependent on the amount of solids present in the sample.

Place the evaporating dish in a drying oven for one hour at 103°C. Transfer the dish to a dessicator and cool for 45 to 60 minutes. Obtain the weight, in mg, of the dried sample.

Calculation

$$\text{Total solids (mg/l)} = \frac{(G - T) \times 1{,}000}{V}$$

where

G = mg (g x 1000), dish + sample after drying
T = mg (g x 1000), dish only (tare weight)
V = ml sample

Reference

Standard Methods (14th ed), pp 91-92.

3.5182 TOTAL FIXED SOLIDS

Apparatus

In addition to the items required for the total solids determination, a muffle furnace, capable of sustaining 600°C, is required.

Procedure

Place the dish containing the total solids residue in a muffle furnace preheated to 600°C. Avoid loss of sample due to sudden ignition by introducing the dish slowly into the furnace. Heat the sample for 20 minutes. Remove the dish from the furnace and allow it to cool for a few minutes before placing it into the dessicator. Allow the sample to cool to room temperature (45 to 60 minutes) and weigh.

Calculation

$$\text{Total Fixed Solids (mg/l)} = \frac{(R - T) \times 1{,}000}{V}$$

where

R = mg (g x 1000), dish + sample after combustion
T = mg (g x 1000), dish only (tare weight)
V = ml sample

Reference

Standard Methods (14th ed.), p 95.

3.5183 TOTAL VOLATILE SOLIDS

Ignition of the total solids residue results in the combustion or organic material, leaving a residue of inorganic salts (total fixed solids). The total volatile solids content of the wastewater sample is, therefore, represented by the weight lost after combustion.

Calculation

$$\text{Total volatile solids (mg/l)} = \frac{(G - R) \times 1{,}000}{V} \qquad (1)$$

where

G = weight (mg) of dish + sample after drying
R = weight (mg) of dish + sample after combustion
V = ml sample

or

Total volatile solids (mg/l) = Total solids – Total fixed solids (2)

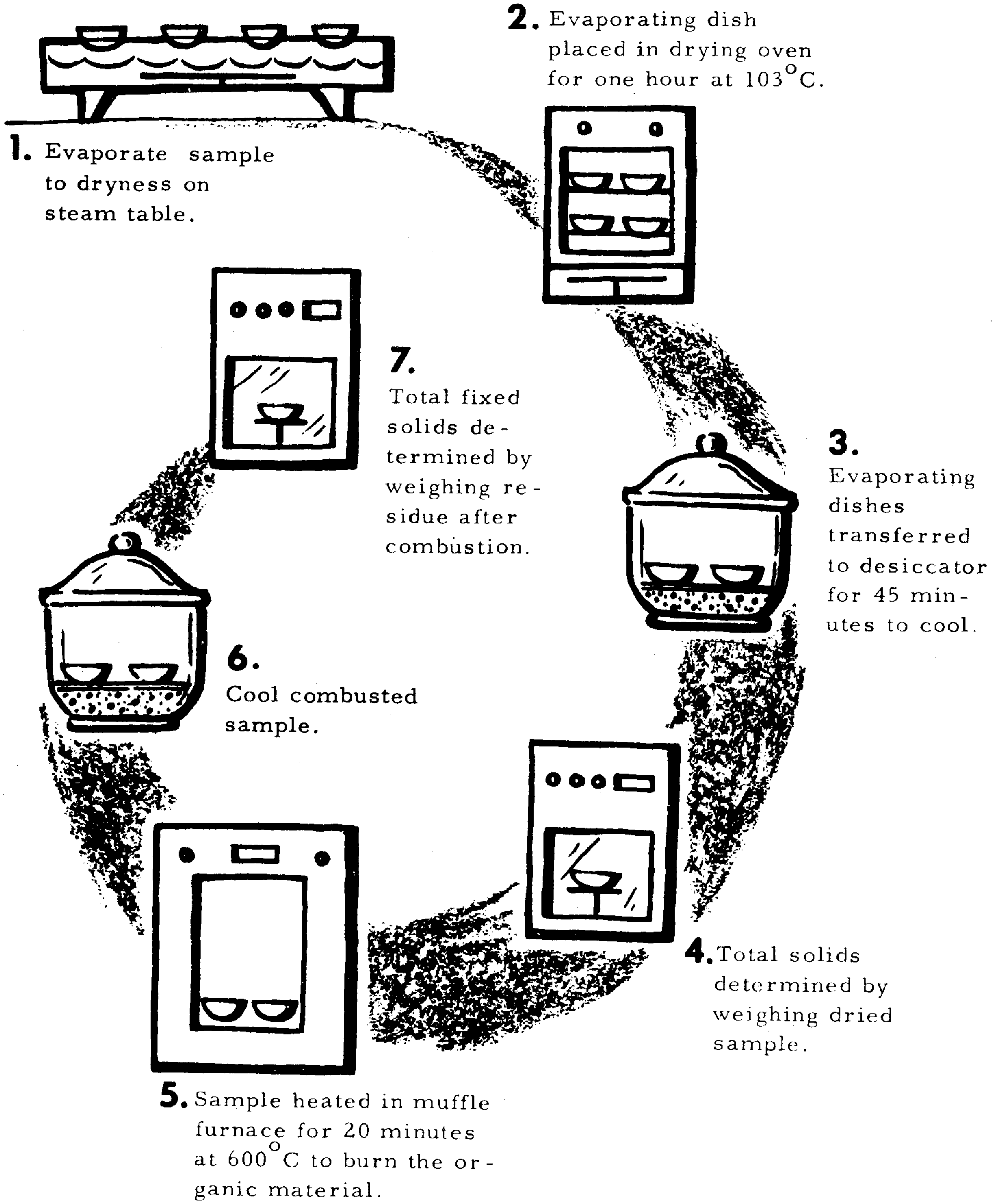
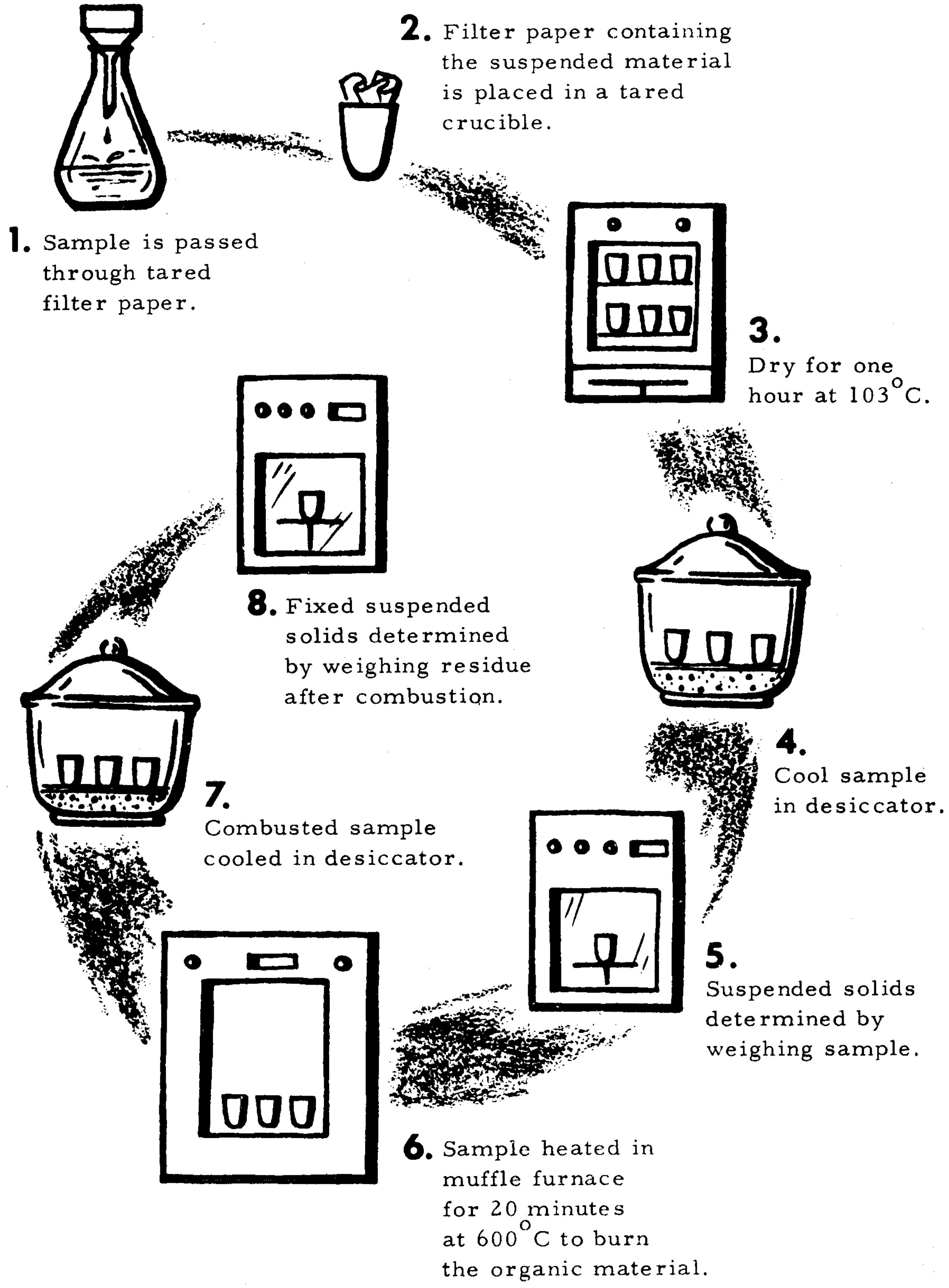


Figure 3.15. Steps in the determination of total and fixed solids. (Total Volatile Solids = Total Solids—Total Fixed Solids)

3.519 Solids – Suspended

The suspended solids determination measures all insoluble (filtrable) material contained in a wastewater sample. This includes insoluble inorganic salts and organic material, such as raw product fragments and microorganisms which may be present in biological treatment systems. The suspended solids content of an activated sludge system is used as an index for determining the operating efficiency of the treatment system. The test is also important to pollution abatement officials since suspended solids are responsible for creating turbid or cloudy conditions in receiving waters, as well as in the wastewater itself. The steps to be followed in the suspended solids determination are illustrated in Figure 3.16.



1. Sample is passed through tared filter paper.

2. Filter paper containing the suspended material is placed in a tared crucible.

3. Dry for one hour at 103°C.

4. Cool sample in desiccator.

5. Suspended solids determined by weighing sample.

6. Sample heated in muffle furnace for 20 minutes at 600°C to burn the organic material.

7. Combusted sample cooled in desiccator.

8. Fixed suspended solids determined by weighing residue after combustion.

Figure 3.16. Steps in the determination of suspended and fixed solids. (Volatile Suspended Solids = Total Suspended Solids – Fixed Suspended Solids)

3.5191 TOTAL SUSPENDED SOLIDS

Apparatus

1. Gelman filter funnel: borosilicate glass, 47 mm (catalog no. 4370), or equivalent.
2. Glass fiber filters (Type A glass), Gelman Instrument Company.
3. Filtering flask, 500 or 1000 ml.

Procedure

Place a glass fiber disc in the filter funnel. Rinse the filter, under vacuum, with 10-15 ml distilled water. Shut off vacuum, remove the filter disc from the funnel (using forceps), and dry at 103°C for 1 hour (30 min in a mechanical convection oven). Cool to room temperature in a dessicator (about 30 min) and weigh to the nearest 0.1 mg.

Carefully measure out a well-mixed sample with a wide-tip pipette or a cut-down volumetric flask. Vacuum filter the sample through the tared filter disc. While the vacuum is still on, rinse the filter with 10 ml distilled water to remove soluble salts. The sides of the filter funnel should be washed free of all material

Shut off vacuum, remove the filter disc, dry and weigh as prescribed above.

Calculation

$$\text{Total suspended solids (mg/l)} = \frac{\text{Gross weight (mg)} - \text{Tare weight}}{\text{ml sample}} \times 1000$$

3.5192 FIXED AND VOLATILE SUSPENDED SOLIDS

Procedure

Place the filter disc containing the total suspended solids into a tared crucible (platinum or silica). Ignite the crucible for 15-20 minutes in a pre-heated muffle furnace at 600°C. Allow the crucible to cool partially and place in a dessicator.

Cool to room temperature (45-60 min) and weigh the crucible and ash to the nearest 0.1 mg.

Calculations

Fixed suspended solids, FSS:

$$\text{FSS (mg/l)} = \frac{\text{Gross wt after ignition (mg)} - \text{Tare wts}}{\text{ml sample}} \times 1000$$

Volatile suspended solids, VSS:

$$\text{VSS (mg/l)} = \text{Total suspended solids (mg/l)} - \text{FSS (mg/l)}$$

3.520 Solids – Dissolved

The dissolved solids determination is a measure of the solids contained in the fluid which passes through a filter paper. If both total and suspended solids determinations are conducted, the dissolved solids content may be found by the difference between the two results, as illustrated in Figure 3.17. When a suspended solids determination is conducted alone, the filtrate (the liquid which passes through the filter) may be used to obtain the dissolved solids content by following the procedure for total solids, Section 3.518.

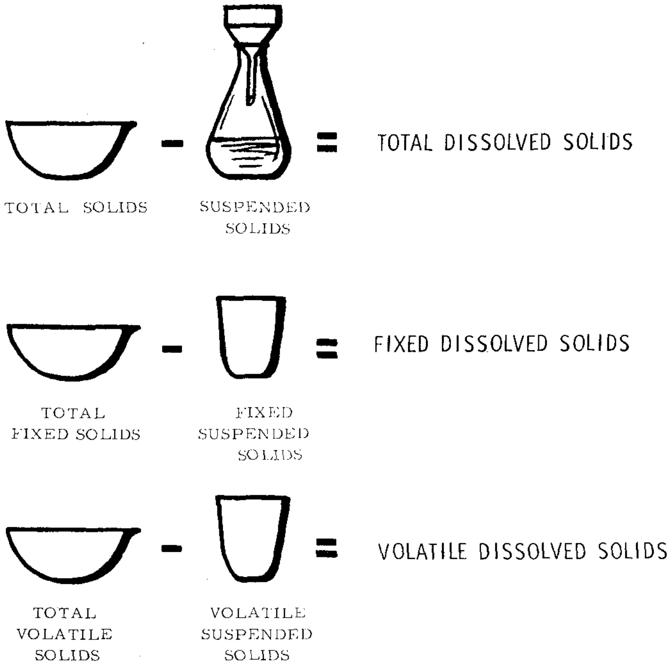


Figure 3.17. Determination of dissolved matter.

3.521 Surfactants (Anionic)

The use of synthetic detergents containing surface-active agents, or "surfactants", has gained wide-spread popularity for general cleaning purpose. These compounds are largely responsible for froth or foam which has become a common sight in polluted streams. A concentration of 1 mg/l surfactant can produce a light froth. For this reason water pollution control agencies are placing increasingly stringent requirements on the discharge of wastewaters containing surfactants.

The most widely used surfactant has been alkyl benzene sulfonate (ABS), a non-biodegradable compound. Due to the increasingly serious problem of water pollution, the soap and detergent industry has replaced much of the ABS with linear alkylate sulfonate (LAS) surfactant. The latter compound is biodegradable and is, hence, reduced to non-frothing components in biological waste treatment systems.

The method discussed in this section is applicable to both types of surfactants. Reference materials for ABS and LAS are available from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268.

Apparatus

1. Separatory funnels, 500 ml, preferably with teflon stopcocks.
2. Spectrophotometer, capable of measuring at 652 mμ with a light path of 1 cm or longer.

Reagents

1. Standard ABS or LAS solution. Prepare a stock solution by weighing an amount of reference material equal to 1.000g surfactant. Dissolve in distilled water and dilute to 1,000

ml. Prepare the standard surfactant solution by diluting 10.00 ml stock solution to 1,000 ml with distilled water. Equivalence: 1.00 ml = 10.0 μg surfactant.

2. Phenolphthalein indicator solution. Dissolve 5g phenolphthalein in 500 ml 95% ethyl alcohol and 500 ml distilled water. Add 0.02N NaOH dropwise until a faint pink color is attained.
3. Sodium hydroxide, 1 N. Dissolve 40 g NaOH in distilled water and dilute to 1 liter.
4. Sulfuric acid, 1 N. Cautiously add 28 ml concentrated H_2SO_4 to about 500 ml distilled water. Dilute to 1 liter.
5. Chloroform, reagent grade.
6. Methylene blue reagent. Dissolve 0.1 g methylene blue (Eastman No. P573, or equivalent) in 100 ml distilled water. Pipette 30 ml into a 1-liter volumetric flask. Add 500 ml distilled water, 6.8 ml conc H_2SO_4 and 50 g monobasic sodium phosphate monohydrate, $NaH_2PO_4 \cdot H_2O$. Shake until completely dissolved and dilute to 1,000 ml.
7. Wash solution. Add 6.8 ml conc H_2SO_4 to 500 ml distilled water in a 1-liter volumetric flask. Add 50 g $NaH_2PO_4 \cdot H_2O$ and shake until completely dissolved. Dilute to 1,000 ml.

Procedure

Preparation of standard (calibration) curve. Pipette 0.00, 1.00, 3.00, 5.00, 7.00, 9.00, 11.00, 13.00, 15.00 and 20.00 ml of the standard surfactant solution into separate separatory funnels. Dilute each to a final volume of 100 ml. Treat each standard as described below and plot a calibration curve (mg surfactant *vs.* absorbance).

Sample volume. Using the table, select the appropriate volume of sample on the basis of expected surfactant concentration.

Expected concentration mg/l	Sample volume ml
0.025-0.080	400
0.08 -0.4	250
0.4 -2.0	100
2 -10	20.0
10 -100	2.0

If the sample volume taken is less than 100 ml, dilute to 100 ml with distilled, otherwise use the entire volume for extraction.

Extraction and color development. Add 1-2 drops phenolphthalein indicator to the sample. Make the solution alkaline with NaOH. Then discharge the red color using H_2SO_4. Transfer the solution to a separatory funnel.

Add 10 ml chloroform and 25 ml methylene blue reagent. Shake vigorously for 30 seconds, then allow the phases to separate. Draw off the chloroform layer into a second separatory funnel. Rinse the delivery tube of the first funnel with a small amount of chloroform. Repeat this extraction procedure two more times, using 10 ml chloroform for each extraction. Add an additional 25 ml methylene blue reagent if the color in the water phase becomes faint. Combine all extracts in the second separatory funnel.

Add 50 ml wash solution to the second separatory funnel. Shake vigorously for 30 seconds, then allow the phases to separate. Draw off the chloroform layer through glass wool into a 100-ml volumetric flask. Wash the solution in the separatory funnel two more times, using 10 ml chloroform for each wash. Combine all washings in the 100-ml volumetric flask. Rinse the glass wool and funnel with chloroform, collecting this volume directly in the volumetric flask. Dilute to the mark with chloroform and mix well.

Measurement. Determine the absorbance of the solution at 652 mμ, using a chloroform blank.

Calculation

$$\text{mg/l surfactant} = \frac{\text{mg surfactant x 1,000}}{\text{ml sample}}$$

Report as ABS or LAS.

Reference

Standard Methods (14th ed.), pp 600-603.

3.522 Standardizing Analytical Reagents

SODIUM HYDROXIDE SOLUTION, 0.02N

Reagent

Standard potassium biphthalate solution, 0.0200N. Dry a quantity of anhydrous $KHC_8H_4O_4$ (primary standard grade) for 2 hours at 120°C. Cool to room temperature in a dessicator. Dissolve 4.085 g $KHC_8H_4O_4$ and dilute to 1,000 ml with CO_2-free distilled water.

Procedure

Pipette 10.0 or 20.0 ml standard $KHC_8H_4O_4$ solution into a 125-ml erlenmeyer flask or a 50 or 100-ml beaker. Add 2-3 drops phenolphthalein indicator and titrate with 0.02N NaOH to the first appearance of a permanent pink color, or to the electrometric endpoint of pH 8.3.

Calculation

$$\text{Normality NaOH} = \frac{\text{ml } KHC_8H_4O_4 \text{ x } 0.020}{\text{ml NaOH}}$$

SULFURIC OR HYDROCHLORIC ACID, 0.02N

Reagent. Use one of the following:

1. Standard sodium carbonate solution, 0.0200N. Dry a quantity of anhydrous Na_2CO_3 (primary standard grade) for 1-2 hours at 140°C. Cool to room temperature in a dessicator. Dissolve 1.060 g Na_2CO_3 and dilute to 1,000 ml with CO_2-free distilled water.
2. Standard sodium hydroxide solution, 0.02N. This solution must have been recently standardized.

Procedure

Pipette 10.0 or 20.0 ml 0.0200N Na_2CO_3 or NaOH solution into a 125-ml erlenmeyer flask or a 50 or 100-ml beaker. Add 2-3 drops phenolphthalein indicator and titrate with 0.02N H_2SO_4 or HCl to the disappearance of the pink color, or to the electrometric endpoint of pH 8.3.

Calculation

$$\text{Normality of acid} = \frac{\text{ml (}Na_2CO_3 \text{ or NaOH x 0.02}}{\text{ml acid}}$$

EDTA SOLUTION, 0.01M

Reagents

1. Standard calcium solution. Dissolve 1.000 g anhydrous calcium carbonate, $CaCO_3$, powder (primary standard or reagent grade) in a minimum amount of 1 + 1 HCl. Dilute to 1,000 ml with CO_2-free distilled water. Equivalence: 1.00 ml = 1.00 mg $CaCO_3$.
2. Calcium determination reagents.
3. Hardness determination reagents.

Procedure

For Calcium determination. Pipette 10.0 ml standard calcium solution into a porcelain dish. Add 2.0 ml NaOH (IN) solution followed by 1-2 drops murexide indicator. Titrate with EDTA solution to the murexide endpoint.

For Hardness determination. Pipette 10.0 ml standard calcium solution into a porcelain dish. Dilute to about 25 ml with distilled water. Add 1 ml buffer solution, followed by 1-2 drops indicator solution. Slowly add the EDTA titrant until the last reddish tinge disappears and the solution is blue.

Calculation

$$\text{mg } CaCO_3 \text{ equivalent to 1.00 ml EDTA} = \frac{10.0}{\text{ml EDTA}}$$

SODIUM THIOSULFATE, 0.025N

Reagents

1. Potassium iodide, reagent grade crystals.
2. Sulfuric acid solution; 1 + 9 (H_2SO_4 + H_2O).
3. Standard potassium biniodate solution, 0.025N. Prepare a 0.1N stock solution by dissolving 3.249 g $KH(IO_3)_2$ in distilled water and diluting to 1,000 ml. Dilute 250 ml stock solution to 1,000 ml for the standard solution.
4. Starch indicator.

Procedure

Dissolve about 2 g KI in a 500-ml erlenmeyer flask with 100 to 150 ml distilled water. Add 10 ml H_2SO_4 solution, followed by 20.0 ml standard $KH(IO_3)_2$ solution. Dilute to 200 ml and titrate the liberated iodine with sodium thiosulfate titrant until a pale yellow color is obtained. Add starch and complete titration to the endpoint indicated by the disappearance of the blue color.

Calculation

$$\text{Normality } Na_2S_2O_3 = \frac{0.50}{\text{ml } Na_2S_2O_3}$$

SECTION 4

WASTEWATER TREATMENT AND DISPOSAL

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SECTION 4
WASTEWATER TREATMENT AND DISPOSAL

LIST OF FIGURES

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4.0

INTRODUCTION AND DESCRIPTION

The purpose of this section is to familiarize the reader with technologies currently available for and generally appropriate to treatment and disposal of wastewaters generated from food processing operations. Alternative technologies for pretreatment, full treatment, land treatment and residual solids disposal are reviewed. Principal characteristics of alternative treatment systems are described and compared to facilitate selection of the treatment system most appropriate to the particular needs of the specific situation. It is intended that this section give the reader a general understanding of the following topics:

1. Pretreatment technology
2. Treatment technology required to meet present and future effluent requirements
3. Land treatment and disposal methods
4. Final discharge constraints
5. Residual solids conditioning and disposal methods
6. General costs of pollution control
7. Potential operating problems.

The information presented is based primarily on the authors' experience which includes many years of general engineering practice in the food processing industry. This section presents only limited detail regarding the theory of treatment processes. More detailed and specific information (as needed for design of systems) can be found in textbooks, EPA publications, State publications, National Canners Association (NCA) publications and numerous other periodicals. A comprehensive, annotated list of references is available in the supplemental volume, Guide to Literature on Waste Management for the Food Processing Industry, 1900-1975. Additionally, the Journal of the Water Pollution Control Federation presents an annual review of literature on treatment of food processing wastewaters.

The appropriateness of any treatment technology to a specific situation and the design of a suitable treatment and/or disposal system in any given instance are best determined by competent engineers. The services of registered professional engineers are required by most states for design of treatment facilities discharging to public waters. One means of locating qualified professional engineering firms providing these services is through contact with state regulatory agencies. Addresses for these agencies may be found in Section 6.2.

General design criteria for many systems discussed are presented in tables throughout this section. This information can help the reader determine the adequacy of alternative systems in meeting a given treatment objective and can be used to develop preliminary treatment unit sizes. However, the information should not be used directly for design.

Costs summaries are also given for the more significant treatment processes discussed. The costs are developed for a hypothetical food processing plant producing one million gallons per day (mgd) of wastewater and operating for *90 days* each year. The estimates are presented to illustrate the relative magnitude of various treatment processes and should not be used to project actual construction costs.

A majority of food processors discharge into publicly owned systems. The information on pretreatment technology (Section 4.1) and discharge to public sewers (Section 4.45) will be of particular value to these processors.

4.01 Sources of Waste

A first step in every wastewater management program should be the cataloguing of wastewater sources. Sources need to be first catalogued by general categories such as process, cooling, runoff, and sanitary. These general source classifications need to be further catalogued by their individual component sources such as, for process flows, peeling, blanching, etc. Section 1.2 of this Guide presents a discussion of wastewater sources throughout the industry, together with information on typical wastewater quantities and characteristics by individual source.

4.02 Regulations

Food processors must meet the discharge requirements of one or more governmental agencies: (1) federal, (2) state, and (3) local. A discussion of discharge requirements is presented in Section 1.11. The information presented here is very general and the reader is referred to the appropriate regulatory agency for current details.

Each industry discharging to a receiving water must have a permit under the National Pollutant Discharge Elimination System (NPDES permit). Industries discharging to land or to public sewers may also be required by the state or local sewerage agency to have a discharge permit. Although the EPA guidelines focus on process wastes, permits set regulations on all discharges – including cooling water, sanitary waste, and storm drainage. The guidelines are set for the following characteristics:

- BOD
- Total Suspended Solids (TSS)
- Grease and Oil
- pH
- Fecal Coliform Count

Oil and grease limitations are also set for the following products:

- Added Ingredients
- Baby Foods
- Chips (potato, corn, tortilla)
- Ethnic Foods
- Jams/Jellies
- Mayonnaise and Dressings
- Soups
- Tomato – Starch – Cheese Canned Specialties

Although the guidelines discussed in this manual refer generally to wastewater discharged into receiving waters, they also affect processors discharging into a public sewer. The law requires that all industries meet the guidelines. A food processor discharging to a public sewer meets its treatment obligation through the use of the joint public-industry treatment plant operated by the servicing sewerage agency or city. If the sewerage agency's plant does not adequately treat the waste water, processors may be forced to provide treatment facilities to make up the difference.

Each state with an EPA certified pollution control program issues NPDES permits. EPA issues permits in states without a certified program. EPA guidelines represent the minimum standard or the maximum permissible discharge. The individual states then consider quality of receiving waters when establishing *additional* limits. Therefore, *many state requirements are more restrictive* then EPA guidelines. Additionally, some states require a state discharge permit even for industries discharging to publicly owned treatment works.

Local requirements are primarily in the form of sewer ordinances that apply to sewer users. Ordinances are intended to prevent: (1) blockages of and damage to the collection system, (2) hazards to workers in the sewers and at the treatment plant and (3) interferences with the treatment process. Ordinances contain specific limits on heavy metals, toxic compounds, oil and grease, temperature, pH, and other characteristics. Ordinances set the basis for sewer user charges and requirements for flow measurement, sampling, sample storage, and testing. Copies of sewer ordinances are always available to industrial users.

Processors discharging to public sewerage systems see another aspect of local requirements – sewer service charges. All sewerage agencies charge for the use of their sewers and treatment plants. The basis and amounts of charges do, and will for some time to come, vary greatly from locale to locale. The largest contributing factor to this variation is the body of regulations set by EPA for federally assisted treatment project construction. If a sewerage agency or city is not receiving federal funds, then the sewer charge can be nominal, perhaps covering only a fraction of the operation and maintenance costs associated with the plant. In this case the basis of charge can be almost anything – from a flat rate to a charge proportional to the floor area of the plant. When, however, a public agency is receiving federal funds for treatment plant construction, service charges usually rise. EPA requires that industry pay its "fair share" of the operation and maintenance and the capital costs of the treatment plant. Industry's "fair share" is calculated in proportion to the amount of waste (usually flow, BOD, and suspended solids) it contributes to the treatment plant.

Processors should make it a point to understand the ordinances under which they are discharging to a public sewerage system and determine the effect of EPA grant regulations (if any) on charges.

4.03 Need For Prior Information

Design of wastewater treatment and/or disposal systems is based upon (1) the volume of wastewater requiring treatment, (2) the physical and chemical characteristics of the wastewater, and (3) the degree to which the wastewater must be treated as established by a comparison of discharge requirements with raw wastewater characteristics. It is necessary that the foregoing information be developed before considering treatment and discharge alternatives appropriate to the situation at hand.

Methods for determining the volume of wastewater, both as total plant effluent and as flow from individual unit operations, are described in Section 3.3. Procedures for developing data to characterize wastewater are also outlined in Section 3. Since treatment and disposal costs are directly related to these measurements, it is important to develop these data for individual inplant sources of wastewater as well as for the combined plant effluent.

4.04 Initial Steps

The importance of cataloguing all sources of wastewater originating within the limits of a processing site was alluded to in Section 4.01. Section 1.21 presents information on the quantity and character of wastewater typically associated with individual wastewater sources, by commodity, within the industry. The initial step in implementing or modifying any wastewater management program will be to catalogue the wastewater sources and, through study of Section 1.21, become familiar with typical wastewater volumes and characteristics associated with these individual wastewater sources.

Volume and character measurement of each wastewater source should follow the "desk top" study described above. A measurement and characterization of the total combined wastewater flow should run concurrent with that of the individual sources to assess the impact of in-plant changes.

Prior to consideration of new treatment systems or expansion of existing treatment works, an effort to reduce the volume and strength of the plant effluent should be made. Measures which can be taken toward this end, as discussed in Section 2, are summarized below:

1. Wherever possible, clean wastewaters (such as evaporator condensate and can-cooling water) should be segregated and separately discharged or reused.
2. Avoid indiscriminate use of water – e.g., unattended hoses, excessive overflows from flumes, washers, tanks, etc.
3. Conserve water through recirculation and extensive reuse, thereby concentrating pollutants in minimum volumes of water.
4. Implement process modifications and procedural changes to minimize wastewater generation and product – water contact, such as by use of dry cleaning techniques together with dry product and dry waste conveyance systems.

After all practical initial-step measures have been taken, the plant effluent should be remeasured and reanalyzed. These data can then be used for: (1) design purposes if new treatment facilities are contemplated, (2) revising wastewater load and associated treatment efficiency expectations, if an existing treatment system is being utilized, or (3) reaching an agreement on or estimating service charges associated with discharge to a public sewerage system.

4.05 Treatment and Disposal Alternatives

There are basically only two reasons to treat wastewater – to reduce sewer service charges or to comply with an effluent standard set by the EPA, the state, or the local agency providing sewerage service. Once the need to treat is established, three options can be used:

- Install pretreatment, discharging the partially treated effluent to the public sewer.
- Install full treatment, discharging the treated effluent to a water course.
- Discharge to land.

Unless the processor is building a new plant, all of these options are not usually available.

Pretreatment differs from full treatment in that pretreatment provides partial treatment of the wastewater with subsequent "final" treatment being provided by the public sewage treatment plant. Full treatment, on the other hand, implies that the processor provides all necessary treatment to and has full control of the treatment of the wastewater from its points of generation to its point of discharge back into the environment.

Wastewater treatment processes are grouped into three categories – primary, secondary and tertiary. Each step removes a greater quantity of pollutants than the preceeding step. Additionally, each step, by virtue of its pollutant removal, renders the wastewater sufficiently "clean" for introduction into the ensuing step (Figure 4.01).

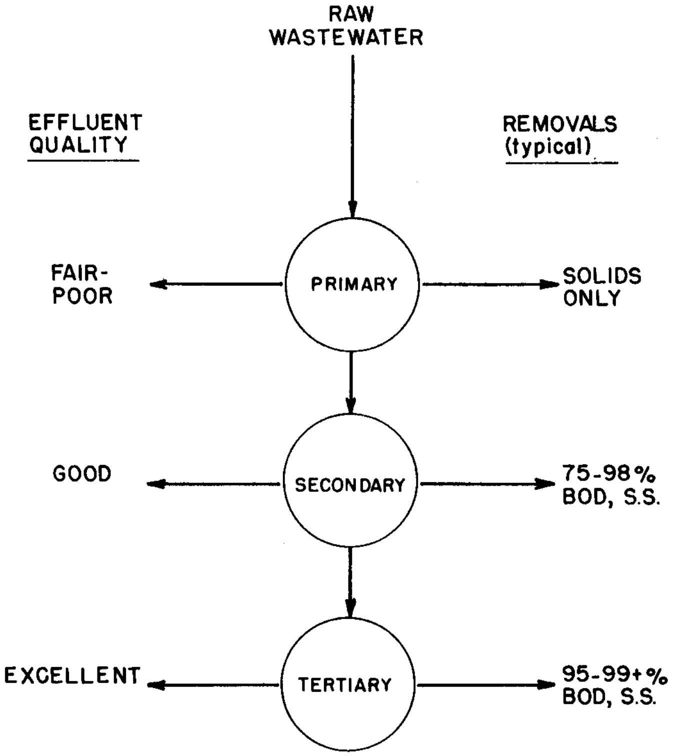


Figure 4.01. Degrees of treatment by progressively higher technologies.

4.051 PRIMARY TREATMENT

Primary treatment systems are designed to effect solids-liquid separation. BOD associated with the removed solids is, of course, also removed, while BOD in the soluble phase, the bulk of the BOD load from fruit and vegetable processing, is not reduced. Equipment used for primary treatment includes screens, clarifiers, and air flotation devices.

4.052 SECONDARY TREATMENT

Most BOD associated with food processing wastewater is removed in secondary treatment. Secondary treatment systems appropriate for use by food processors are generally restricted to those employing biological processes. The alternative physical-chemical treatment processes are not generally applicable to secondary treatment of food processing wastewaters, except where the BOD is associated principally with suspended solids and very little is in a truly dissolved state. The biological processes most commonly used include activated sludge, aerated ponds, and trickling filters. The most commonly used physical-chemical process is coagulation-flocculation in conjunction with sedimentation or air flotation.

4.053 TERTIARY TREATMENT

Tertiary treatment systems are considered only where an extremely high quality effluent is desired. Wastewaters reclaimed by tertiary treatment may be suitable for reuse in many food processing plant unit operations, particularly ancillary operations such as cooling. While tertiary systems are used principally to remove nutrients, refractory organics and heavy metals from secondary effluents, these systems also reduce effluent BOD and suspended solids concentrations to extremely low levels. The most commonly used tertiary processes include: (1) chemical (lime, alum, or ferric) coagulation and sedimentation; (2) fine or mixed media filtration; and (3) disinfection employing chlorine. Special tertiary processes occasionally applicable include carbon adsorption, ultra-filtration, and reverse osmosis.

4.054 LAND TREATMENT

Individual processes responsible for purification of wastewaters applied to land are similar to those associated with primary, secondary and tertiary treatment. As such, land treatment is really a term used to include all these treatment processes (chemical, physical, and biological) which occur *naturally in soil* and act upon wastewater pollutants as the wastewater moves through the "filter" provided by the cover crop and soil mantle.

4.06 Treatment Costs

As the reader is aware, costs for wastewater treatment are ever changing (increasing). Additionally, treatment costs vary with local conditions (including climate and local philosophy of design), construction, and operation. To further complicate matters and render general cost information of even less credibility, is a variance in costs with wastewater quantity and character. Nevertheless, comparative cost summaries are given in this section for the more significant treatment processes, discussed. As indicated, the costs were developed for a hypothetical food processing plant producing one million gallons per day (mgd) of wastewater and operating for *90 days each year.* The estimates are presented to illustrate the relative magnitude of costs for the various treatment processes and should not be used to project actual costs.

To compute the cost of capital, equal annual payments on a ten-year loan at 12 percent is assumed. This results in ten annual payments, each 17.7 percent of the initial capital cost.

Costs are for October 1975 and assume competitive bids by contractors. The estimates are "order of magnitude" estimates. It is assumed that significant site grading is not required and that good soil conditions exist. Costs do not include those for site acquisition or separate fencing, yard lighting, access roads, and laboratories. The costs associated with start up and shut down have not been included.

Table 4.01 summarizes the costs in this text. The table also includes estimates for costs associated with *180-day* and *360-day* operating seasons. Other assumptions for deriving the examples are either listed in the individual cost tables or given in the text. The operating and maintenance costs as presented include only major direct costs; they do not include any general or corporate overhead or equipment replacement costs.

TABLE 4.01

SUMMARY OF ESTIMATED COSTS

		NUMBER OF OPERATING DAYS PER SEASON					
		90 Days		180 Days		360 Days	
		Annual Cost	¢/1,000 Gal.	Annual Cost	¢/1,000 Gal.	Annual Cost	¢/1,000 Gal.
4.01	Flow Measurement and Screening	$ 15,900	17.7¢	$ 19,100	10.6¢	$ 25,500	7.1¢
4.02	Neutralization	$ 41,300	45.9¢	$ 64,900	36.0¢	$112,100	31.1¢
4.03	Aerated Lagoon	$112,100	125¢	$132,600	73¢	$173,600	48.2¢
4.04	Activated Sludge without Sludge Concentration	$289,150	321¢	$364,150	202¢	$814,150	226¢
4.05	Activated Sludge with Sludge Concentration	$255,850	284¢	$314,350	175¢	$431,350	120¢
4.06	Filtration	$ 51,960	57.7¢	$ 55,960	31.1¢	$ 63,960	17.8¢
4.07	Chlorination	$ 9,525	10.6¢	$ 12,325	6.8¢	$ 17,925	5.0¢

4.1

PRETREATMENT

4.10 INTRODUCTION

Most food processing plants discharging to a public sewer system use some method of pretreatment. In the broadest sense, pretreatment is simply treatment before discharge to a public treatment system. However, pretreatment usually refers to gross solids removal, soil removal or neutralization. Common pretreatment steps are screening, neutralization, or flow equalization, but sometimes more extensive treatment, such as gravity sedimentation or dissolved air flotation, is used.

The following are reasons to pretreat:

Meet ordinance requirements
Reduce costs
Accommodate production increases

Pretreatment is also needed when discharging wastewater to land. Screening prevents the spray nozzles and soil surface from plugging. Removal of grease or neutralization may be required to prevent soil or crop damage. Certain ions may have to be removed or others added to prevent soil or crop damage or ground water contamination.

4.101 ORDINANCE REQUIREMENTS

Pretreatment is often required by city ordinance. Screening is almost always a requirement of the ordinance. Neutralization, flow equalization, and soil removal are also often required.

4.102 REDUCE COSTS

Despite the high rates charged by some cities and other public agencies for using their sewers, it is sometimes difficult to economically justify treatment solely to reduce sewer charges. The main reason for this difficulty is the high cost of solids disposal and the high cost of building and operating small treatment systems. Because of the high cost of industrial capital, the short processing season and other factors, the cost for comparable treatment by food processors alone may be considerably higher. Section 4.45 discusses cost sharing aspects of joint treatment in more detail.

A decision to provide extensive pretreatment or separate treatment should be based on a thorough, after-tax analysis of the costs. If a processor can irrigate part or all of the plant effluent onto nearby land, the cost can be favorable when compared to treatment in a mechanized, publicly owned joint treatment plant.

Presently, recovery of food processing by-products at the end of the pipe is usually less than a "break-even" proposition. For this reason, recovery is only practical if it responds to other requirements for pretreatment or helps to defray some of the pretreatment operating costs. For certain products in livestock-producing areas, screenings and treatment sludges can be recovered and used in animal (cattle, poultry, hogs) feeding operations. If by-product recovery is to be practiced, all sanitary waste must be excluded.

4.103 PRODUCTION INCREASES

Extensive pretreatment can be required as a result of plant expansions. Plants discharging to public systems frequently reach their allocated treatment capacity as a result of increasing waste loads. Presently, the time required to expand a public treatment plant is about five years.

Limitations imposed on cities by the EPA can result in construction of public treatment facilities with limited capacity. For example, the Los Angeles area is designated as a "critical air basin" and only limited expansion capacity is allowed in public treatment plants. If additional reserve capacity were provided, additional growth might occur and further degrade air quality. The result can be a limit on industrial wastewater discharge.

Few processors can wait for a city to provide additional capacity. One option is to pretreat the waste so that the processor's contribution to the public system does not increase as a result of the processing plant expansion.

4.11 Pretreatment Processes

Many processes can be used for pretreatment. The processes that are most frequently used are screens, neutralization systems, flow equalization, and soil removal. Added pretreatment could include sedimentation units, dissolved air flotation units, or even biological treatment units (roughing trickling filters, ponds, etc.). These more complete units are discussed in Section 4.2.

4.111 SOLIDS REMOVAL

As previously discussed, removal of solids from wastewater will reduce the organic and/or physical loads imposed on subsequent treatment systems. Removal of these solids will also minimize problems in public sewers and treatment plants. Public treatment plants are seldom designed to accommodate significant quantities of large and/or heavy solids such as pits, tops and vines. Heavy discharges of these solids plug piping and equipment associated with preliminary treatment units in public facilities.

Organic solids contained in food processing wastewater tend to be reduced in size and solubilize rapidly with time, resulting in an ever smaller portion of the wastewater BOD being associated with the wastewater suspended solids. BOD removals as well as suspended solids removals are maximized by placing solids removal steps as close in time and distance to the wastewater source as possible. The solids removal techniques discussed below are appropriate to pretreatment for solids removal.

4.1111 Screening

Screening is the most common form of pretreatment. Screens remove large particles that might clog sewers or cause problems at the treatment plant. Although fine screens (200 to 400 mesh) can remove large amounts of suspended solids, they also produce wet screenings. Common practical screen sizes are coarser – 20 to 40 mesh.

Screens should be as close as possible to the process producing the waste. Contact time and agitation of solids with water should be kept at a minimum to gain maximum benefits from screening.

The following are often considerations in purchasing screens: (1) initial cost, (2) hydraulic capacity, (3) solids captured, (4) blinding potential, (5) moisture of screenings, (6) operating and maintenance costs, (7) space required, and (8) hydraulic head required.

Four types of screens are commonly used in the fruit and vegetable industry. Vibratory screens are very common. Two variations are the circular units in which solids may be discharged in a spiral toward the center or periphery; and the rectangular, end-feed variation, in which solids are discharged at the lower end. The rectangular, end-feed unit is shown on Figure 4.02. A circular, center-feed unit is shown on Figure 4.03.

Figure 4.02. Rectangular end-feed vibratory screen.

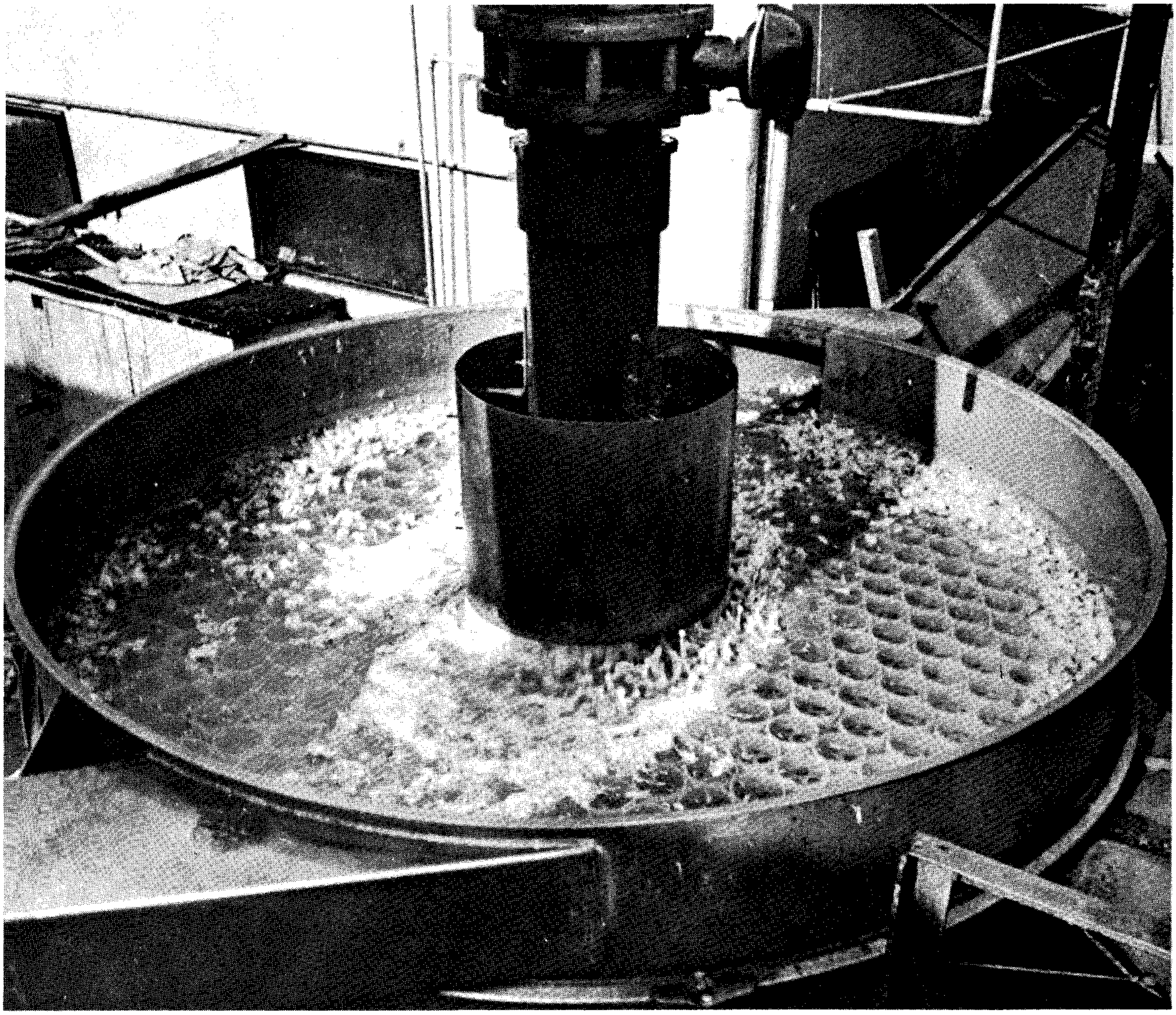


Figure 4.03. Circular center-feed vibratory screen.

The rotary drum screen is also common. These screens may be designed so the flow is from the inside of the drum toward the outside, or the reverse. If the flow is from the inside, then the solids are collected inside the screen and removed by augers, or a trough. In units where the flow is from the outside to the center, the solids are retained on the outer surface of the drum and are removed by a doctor (or scraper) blade. A drum screen is shown on Figure 4.04.

Tangential screens (Figure 4.05) are widely used. The water flows down and through a parabolic screen, but the solids are retained on the surface of the screen and discharged from its lower end.

A recent derivation of the tangential and drum screens is illustrated in Figure 4.06. The wastewater is introduced behind the slotted drum, which rotates forward at the top. Solids are retained on the surface of the drum and scraped off by a blade. The screened wastewater falls through the drum and backwashes the under side before being discharged.

Rotating centrifugal or collar screens can be used when high-solids capture is required. The screens can be very fine, up to 400 mesh. The waste is sprayed under pressure onto the inside of the rotating drum. The water passes through the screen and the solids are collected on the inside of the collar. The solids typically have a high moisture content.

Successful application of screens depends on many variables. The literature is often confusing and contradictory. Screens ordinarily achieve a high removal of settleable and floatable solids, but variable amounts (up to 70 percent) of suspended solids. Proportional but much lesser amounts of BOD are ordinarily removed with the solids.

Location of the waste screen is very important. One option is to collect wastewater in a sump below the floor level of the plant, and then pump the wastewater to the screen. Many screens are located above the solids hopper. These require pumping but usually avoid the need for a solids conveyor. Pumping may reduce screening efficiency by reducing the particle size of suspended solids. Pumps, valves, and piping should be designed to minimize agitation. Another option is to place the screens below the level of the plant drains (if

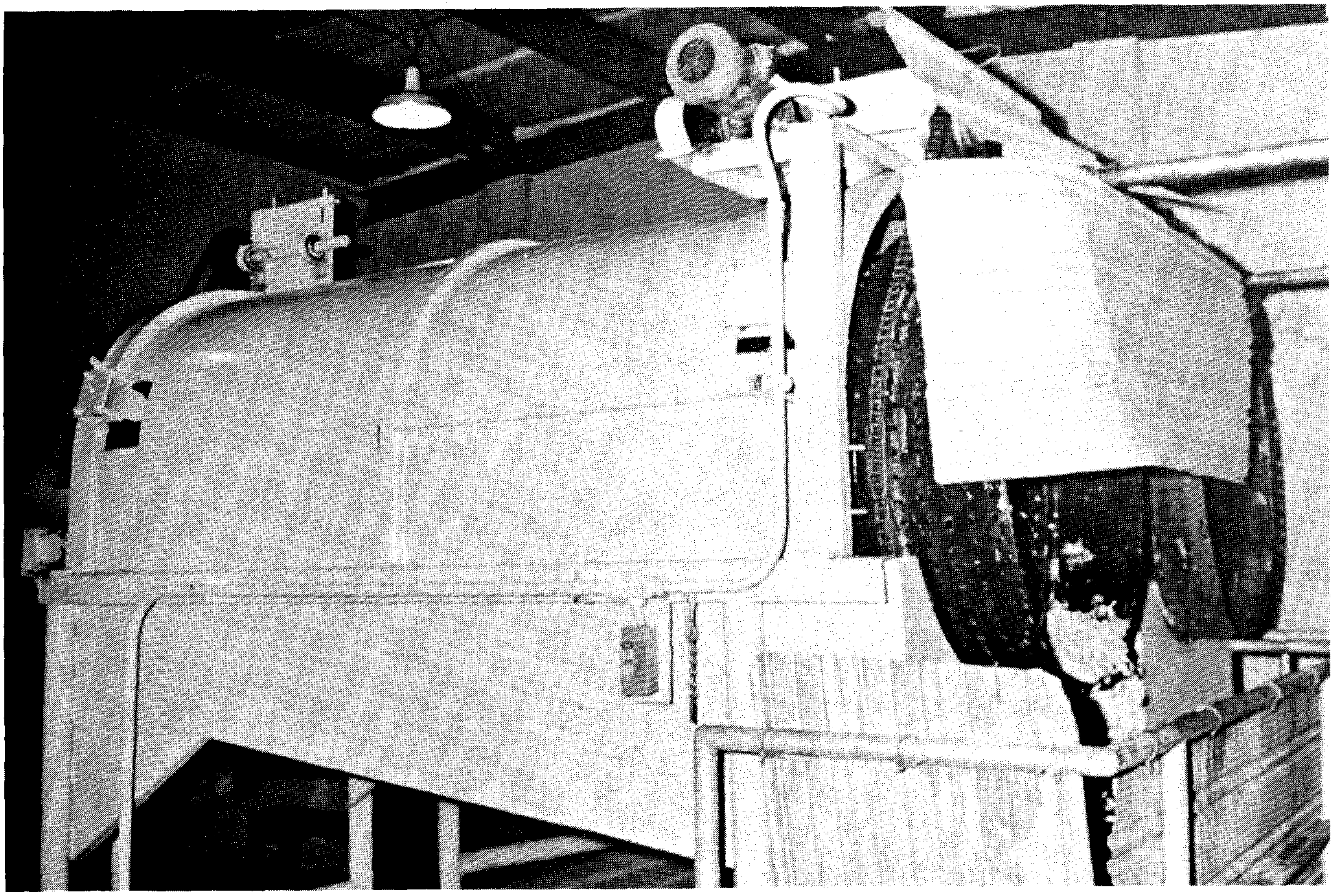


Figure 4.04. Rotary drum screen.

the elevations permit). After screening, the solid waste can be conveyed up to the waste hopper.

Screening is an inexpensive method for removing large solids (greater than about 60 mesh) from wastewater. Compared to other pretreatment methods, screens require only a small space and can usually be easily installed in an existing plant.

An estimate of the costs for screening is given in Table 4.02. These costs are for October 1975 and assume a 20-mesh tangential screen. The estimate assumes that the plant floor drains will not have to be modified to collect all wastewater at one point.

4.1112 Sedimentation – Clarification

Sedimentation in gravity clarifiers is not generally used in pretreatment practice, being more commonly associated with full treatment systems. Detailed discussion of sedimentation-clarification systems, for this reason, is presented in Section 4.221 under Primary Treatment.

Clarifiers may be used to remove, by gravity sedimentation, most (50 to 80 percent) of the small but discrete fruit and vegetable fragments which have passed through a typical 20- to 40-mesh screen. Sedimentation should, where necessary, supplement screening in pretreatment systems but should seldom, if ever, substitute for screening. Chemical aids, such as polymers, may be added to enhance suspended solids removal in sedimentation.

Sedimentation would be far more attractive as a pretreatment unit process were it not for the problems and costs associated with processing and disposing of the solids removed. Unless the solids removed are soil (see Section 4.112) they will be accompanied by large amounts of water; water generally represents 95 to 99 percent of the wet solids weight. Solids dewatering, sufficient to make subsequent transportation and disposal or reuse practical, is costly and operations intensive. See Section 4.5 for a discussion of solids conditioning and disposal.

Despite the above, sedimentation (for other than soil removal) has been appropriately used in pretreatment systems in the past. Circumstances which individually or collectively may point to sedimentation use include:

1. The screened wastewater contains substantial concentrations of settleable organic solids having a significantly high associated BOD.
2. The settleable organic solids have a commercial value (such as for cattle feed) sufficient to at least partially defray costs – a condition not uncommon today.
3. Pretreatment efficiency of solids and/or BOD removal must be increased to conform to limits established for discharge to the public sewer.
4. The pretreated wastewater is to be discharged to land where the solids would lead to soil surface plugging and/or development of nuisance conditions.

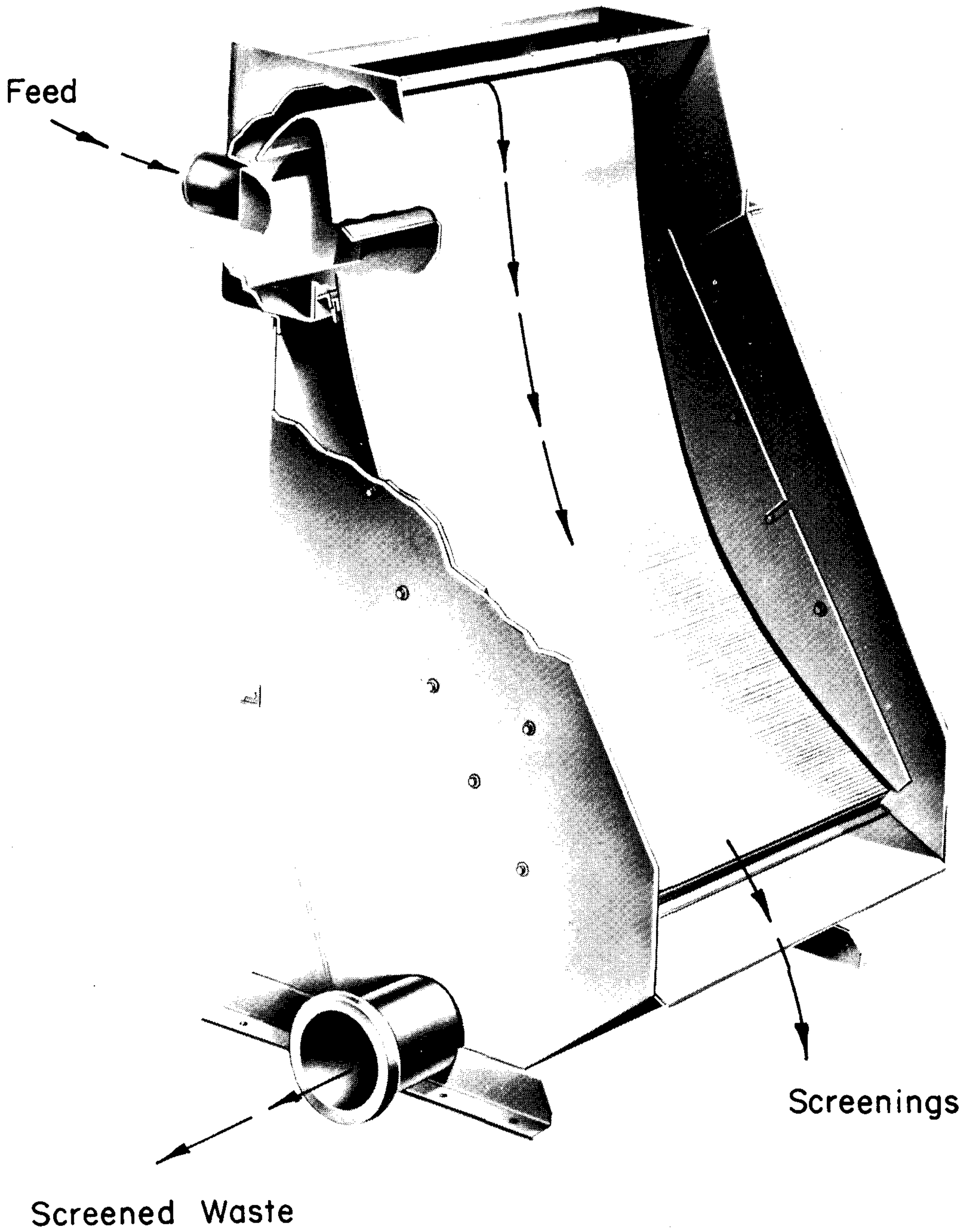


Figure 4.05. Tangential screen (45°).

4.1113 Air Flotation

The reasons for and constraints associated with using air flotation as a pretreatment process are similar to those stated for sedimentation-clarification. Air flotation is also discussed in detail as a "Primary Treatment" unit process under "Full Treatment" in Section 4.222.

4.112 SOIL REMOVAL

Root crops (potatoes, carrots, and beets) and machine harvested crops (tomatoes) introduce large amounts of field soil to a food processor's waste streams. Since the present incentive for field cleaning is slight, each processor has to remove and handle the soil. Public treatment plants are not built to deal with large quantities of soil. The abrasive material accelerates equipment wear, settles in pipelines, and accumulates in the treatment plant's solids handling system (i.e., the sludge digester).

Many ordinances are now being written to require food processors to remove a majority of the soil from their wastewater. Soil may also have to be removed from wastewater before it is irrigated to avoid physical intereference with the irrigation system.

Settling ponds have and can be used for soil removal. Provisions must be made for draining the ponds for solids removal. Odor is a potential problem. The extent of odor production cannot be forecast. In general, the fewer organics

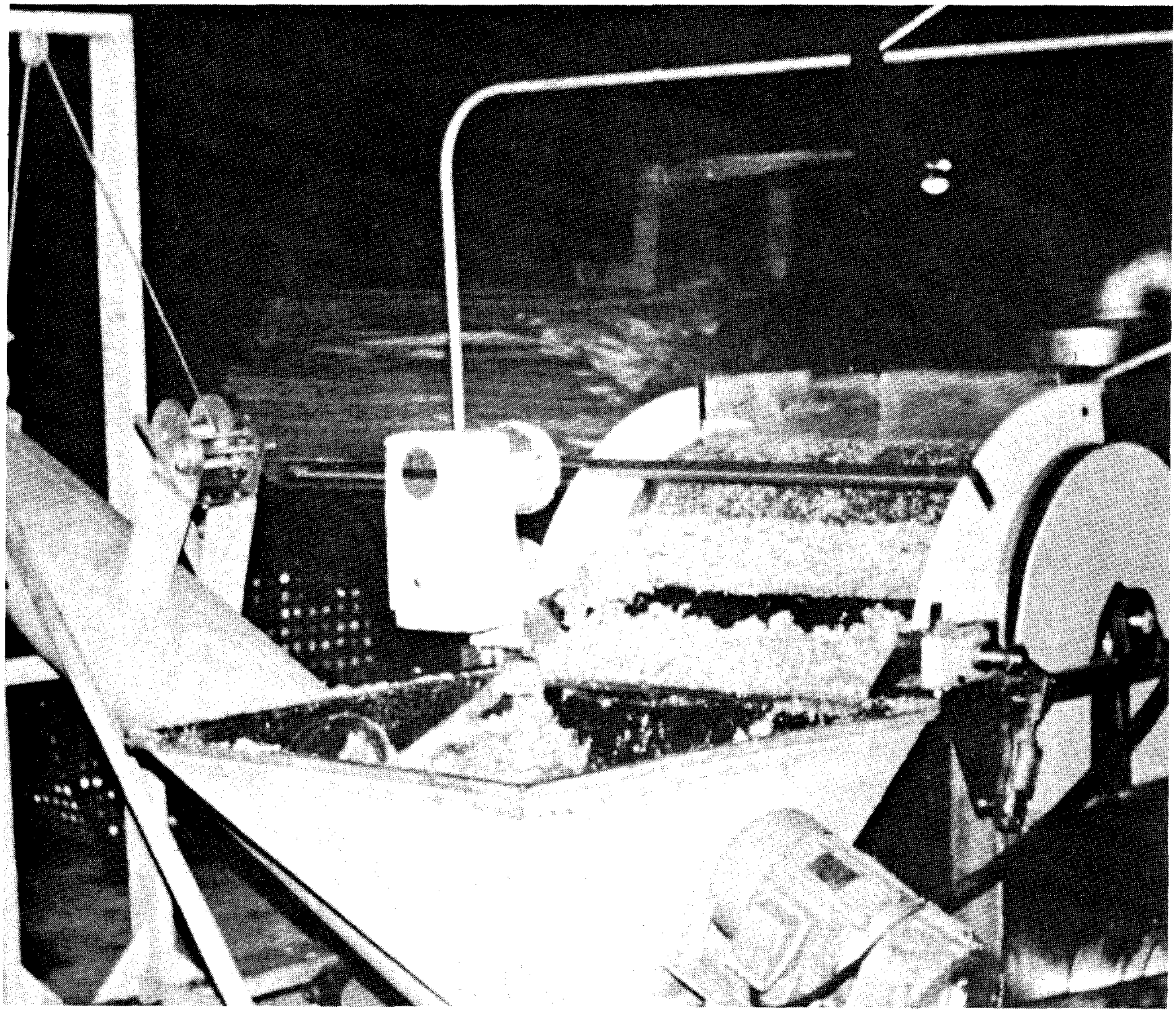


Figure 4.06. Slotted drum screen.

the better; the higher the pH the better; and the shorter the detention time the better. The effluent from settling ponds is often high in BOD and suspended solids.

Where space and disposal of solids is a problem, circular clarifier-thickeners (Figure 4.07) can be used to settle and thicken the soil. Typically, circular clarifier-thickeners will produce a mud two to three times thicker than could be obtained to plain settling ponds. This means that the volume of mud to be disposed of is reduced two to three times.

Grit-removing cyclones have also been tried at some plants. The units are relatively inexpensive, but they must be run at a constant flow to achieve their design efficiency. Cyclones are not as efficient as a well-designed clarifier-thickener and they tend to produce a dilute mud. The system must be designed to withstand abrasion.

Fine (to 400-mesh) screens have also been applied to remove soil. The application is similar to screening. Several screens can be used in series to concentrate the solids. These units approach the efficiency of clarifier-thickeners but are considerably more difficult to operate and maintain, and are usually more expensive.

4.113 NEUTRALIZATION

Most public agencies limit the pH of wastewater discharged into the sewer. This limit is to protect the sewer lines and to ease any pH shocks to the treatment plant. The pH limits are commonly set at 6.5 and 8.5.

Neutralization will normally be required for only those industries processing naturally acidic foods (tomatoes), those using a caustic peeling process (peaches, potatoes, etc.), or those using a brine (cherries, olives).

A reliable neutralization system has two to three mixing tanks, in series, in which an acid or base is added. The acid or base is automatically added, using a metering system controlled from effluent pH readings.

A consistently alkaline waste can be neutralized by using carbon dioxide (CO_2). Boiler stack gas may be a source of CO_2.

A cost estimate for a neutralization system is given in Table 4.03. The costs are for October 1975 and include two mixing tanks, an instrumentation and control system, and chemical storage. The wastewater is assumed to be acidic and

TABLE 4.02

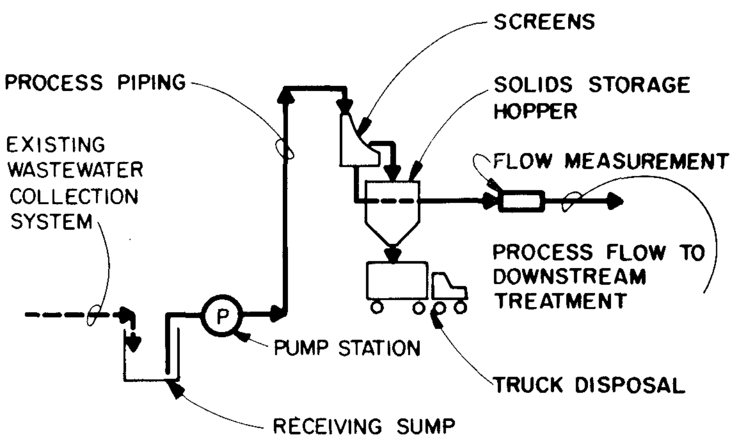
COST SUMMARY FLOW MEASUREMENT & SCREENING

CRITERIA

∘ FLOW:	1 MGD AVERAGE 2 MGD PEAK
∘ BOD:	1000 mg/l
∘ TSS:	1000 mg/l
∘ pH:	4.5
∘ SEASON:	90 DAYS
∘ AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- SOLIDS HAULING AND DISPOSAL AT 4 DOLLARS / cy
- USE OF 20- MESH SCREEN

COSTS

CAPITAL	OPERATION AND MAINTENANCE	
$71,600	LABOR	$700/yr
	DISPOSAL	2500/yr
	TOTAL	$3,200/yr

AMORTIZED CAPITAL PLUS O & M	$15,900/yr
UNIT COST	17.7¢/1000 gal

is neutralized with caustic. Facilities for neutralization with lime or sulfuric acid will differ only in chemical storage and delivery.

Only infrequently will a food processing plant produce a wastewater that exceeds both alkaline and acid limits. In cases where both limits are exceeded, the storage, feed and control system must provide for both acid and base additions. The dual system is more complicated and consequently more expensive.

4.114 FLOW EQUALIZATION

Control of surges in effluent flow is usually not required as a pretreatment measure. However, if flow variations can be smoothed out and accidental spills contained and controlled, screens can be smaller and effluent pH control will be simpler.

Depending on the daily operating mode of the processing plant, variations in instantaneous flow can be from very small to very great (a maximum of 4 times the minimum). Each plant is obviously different, but large variations in flow may be smoothed with a surge tank of about 10 to 20 percent of the total daily flow volume. Settling of solids will be a significant problem in a tank of this size, so the tank must either be mixed or some means provided for solids removal. If solids accumulate, odor will result.

4.115 OIL AND GREASE REMOVAL

High concentrations of oil and grease are characteristics of wastewater from the meat and seafood products industry, the vegetable oil industry, and some specialty food processors, such as those producing frozen french fries and prepared dinners. Pretreatment for removal of grease and oil is often necessary to meet ordinance requirements, reduce the concentration to a level that can be effectively treated in subsequent biological systems, and to prevent accumulation in pipes and on equipment. Oil and grease of animal or vegetable origin are normally more compatible to biological treatment systems and have less of a tendency to coat surfaces than oils of petroleum origin. Even so, oil and grease of animal and vegetable origin can create significant problems in public sewers and treatment plants when discharged in quantity. As a result, many food processors have found installation of oil and grease removal pretreatment systems necessary.

Removal systems normally employ facilities designed to enhance flotation of oil and grease, although some work has been done with filtration. The flotation facilities vary from simple grease traps to dissolved air flotation employing chemical aids.

The simplest removal system is a "grease trap" – a tank with the inlet and outlet located below the surface, providing

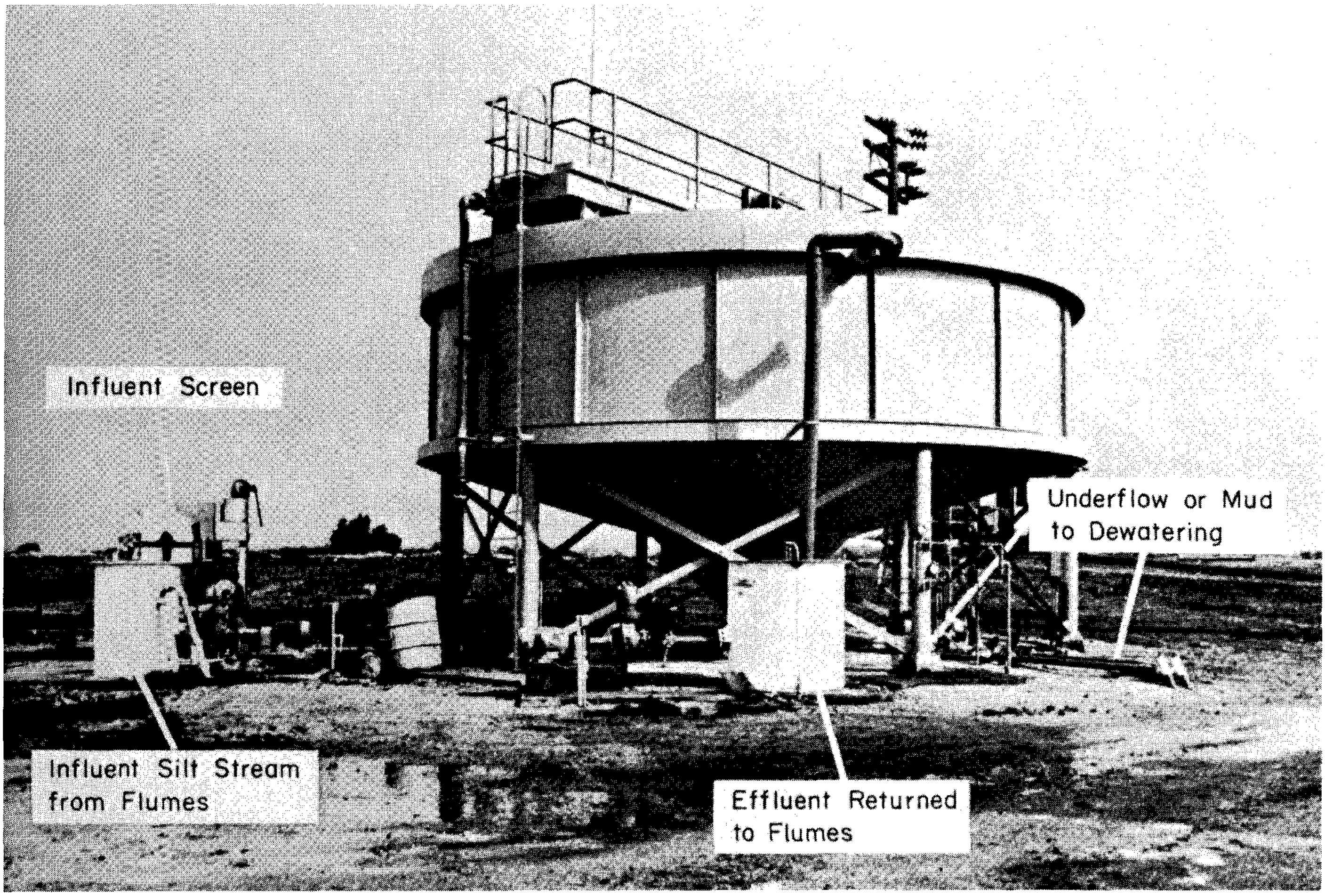


Figure 4.07. Silt clarifier-thickener.

a quiescent area allowing the oil or grease to float. For best operation the trap should be located close to the source, must be large enough to hold expected surges, and must be cleaned regularly. Detention times of 20 to 40 minutes are normally required. The grease trap is useful in removing free oil and grease from small flows but is not effective in removing the emulsified oils.

Removal of non-emulsified or free oil and grease can also be combined with the gravity sedimentation process. The quiescent conditions designed to allow particles with a specific gravity greater than 1.0 to settle will also allow non-emulsified oil and grease to float. Floating material is prevented from flowing into the effluent by surface baffles. Skimmers push the oil and grease into a trough where it is subsequently carried away. Provisions are frequently required to prevent the oil and grease from solidifying and accumulating in the trough and piping.

These provisions may include heat lamps on the trough, heat-tracing tape and insulation on the pipelines and, occasionally, a hot oil recirculation system between the oil or grease collection/storage tank and the trough at the clarifier. The collection/storage tanks frequently require heating to prevent oil and grease solidification. Two-compartment tanks are preferred. The first compartment is used to receive the oil or grease from the clarifier-skimmer trough and provide for its separation from the water which invariably accompanies the oil or grease from the skimmer trough. The second compartment serves to store the oil or grease until pick-up for recovery or disposal.

Dissolved air flotation, as described in Section 4.222, is also used for oil removal. This process complements the tendency for free oil and grease to float by the attachment of fine air bubbles. Air flotation will occasionally remove non-stable oil emulsions without use of chemicals, although most emulsions require chemical addition even when dissolved air flotation is employed.

In the event that emulsified oil must be removed in pretreatment, chemical treatment is generally used in conjunction with gravity sedimentation or dissolved air flotation. Chemicals are commonly used to break emulsions and to flocculate the oil and grease. Chemical selection is dependent on the type of oil or grease being removed as well as other characteristics of the wastewater.

Adsorption filters have also been employed on wastewaters with very high oil concentrations. The removal mechanism is adsorption of the soil onto the media. The filter media is regenerated by a chemical process.

Once the oil has been separated, it has a value as a byproduct, either by the industry from which it originated or by oil reclamation companies. Oil that is not reclaimed can generally be disposed of in landfills.

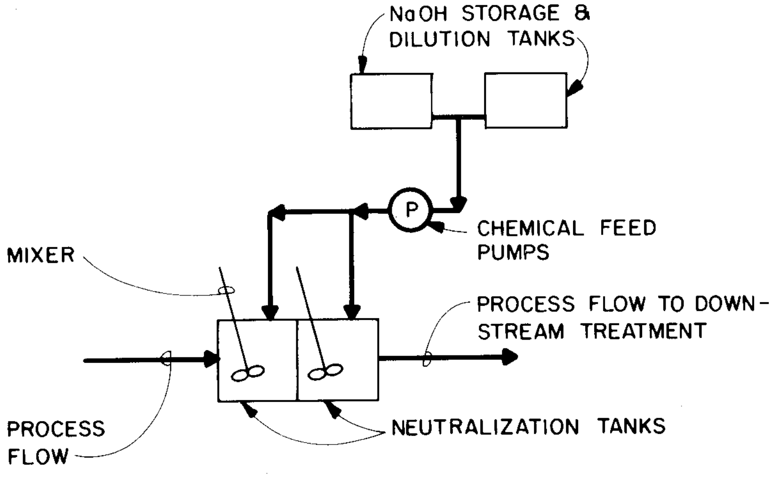
TABLE 4.03
COST SUMMARY NEUTRALIZATION

CRITERIA

° FLOW:	1 MGD AVERAGE 2 MGD PEAK
° BOD:	1000 mg/l
° TSS:	1000 mg/l
° pH:	4.5
° SEASON:	90 DAYS
° AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- NEUTRALIZATION WITH 20% NaOH AT 200 mg/l NaOH
- NaOH COST AT 165 DOLLARS PER ANHYDROUS TON
- TANK TRUCK SHIPPING COST AT 3 CENTS/100 lb LIQUID/MILE WITH 100 MILE SHIPPING DISTANCE
- TWO NEUTRALIZATION TANKS IN SERIES WITH 15 MINUTE AVERAGE RETENTION

COSTS

CAPITAL	OPERATION AND MAINTENANCE	
$100,000	LABOR	$1000/yr
	CAUSTIC (50%)	22,600/yr
	TOTAL	$23,000/yr

AMORTIZED CAPITAL PLUS O & M	$41,300/yr
UNIT COST	45.9¢/1000 gal

4.116 FURTHER PRETREATMENT

If additional pollutant removal of suspended solids or BOD is needed, more complex process units than those discussed to this point must be used. These processes and others are discussed in complete detail in Section 4.2.

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4.2

TREATMENT METHODS

Discharge to public waters (streams, lakes, etc.) requires treatment beyond pretreatment. Moreover, additional treatment may be required for land disposal or discharge to a public sewer.

Treatment processes are divided into three broad categories, based on their ability to remove increasing amounts of pollutants: (1) primary treatment, (2) secondary treatment, and (3) advanced wastewater treatment (tertiary treatment). The processes commonly thought of as being under each of these three categories are listed in Table 4.04. For the treatment of food processing wastewater, primary treatment is used to remove a portion of the suspended solids in the wastewater; secondary treatment is used to remove a portion of the dissolved and suspended solids material; and advanced (tertiary) treatment is used to remove additional amounts of these constituents and treat other constituents. These same processes are used to treat domestic sewage.

Figure 4.08 is a graphical representation of how BOD and suspended solids are removed in various treatment processes. The length of the bars in the figure is semiquantitative. The sum of a pair of bars represents the total amount of solids (or BOD) in the wastewater. The length of the BOD bars should not be compared with the length of the solids bars. BOD is an effect, or demand, exerted by the solids, and may not be in proportion to the mass of solids.

Treatment is accomplished by the removal or conversion of solids. All treatment processes result in sludge production – sludge requiring conditioning and disposal. Conditioning and disposal of sludge is discussed in Section 4.5.

4.21 Requirements For Treatment

In nearly every case the amount of treatment is established by local, state, or Federal treatment and/or effluent standards. However, treatment in excess of governmental regulations could be required as a result of law suits brought by people who claim to be adversely affected by the discharge or operation of a treatment system. Common causes for litigation are odor (air pollution), noise, and ground water contamination.

TABLE 4.04
FULL TREATMENT UNIT PROCESSES

PRIMARY TREATMENT	SECONDARY TREATMENT	TERTIARY TREATMENT
Plain Sedimentation	Stabilization Ponds	Chemical Clarification
Dissolved Air Floration	Aerated Lagoons	Filtration
Chemical Treatment	Activated Sludge	
	ABF/Activated Sludge	
	Trickling Filters	Carbon Adsorption
	Rotating Biological Contactors (RBC)	
	Anaerobic Systems	Ion Exchange
		Reverse Osmosis

4.211 EPA GUIDELINES

The Environmental Protection Agency has completed discharge guidelines for food processors who have their own discharge to public waters. With the exception of seafood processors in remote areas of Alaska, secondary treatment is required for all plants that discharge into the Nation's waterways. By mid-1983 the EPA guidelines may mandate advanced treatment.

The 1977 guidelines for the apple, citrus, and potato processing industries are to be met with secondary treatment. Exemplary secondary treatment plants studied by EPA included the following processes: activated sludge, trickling filter

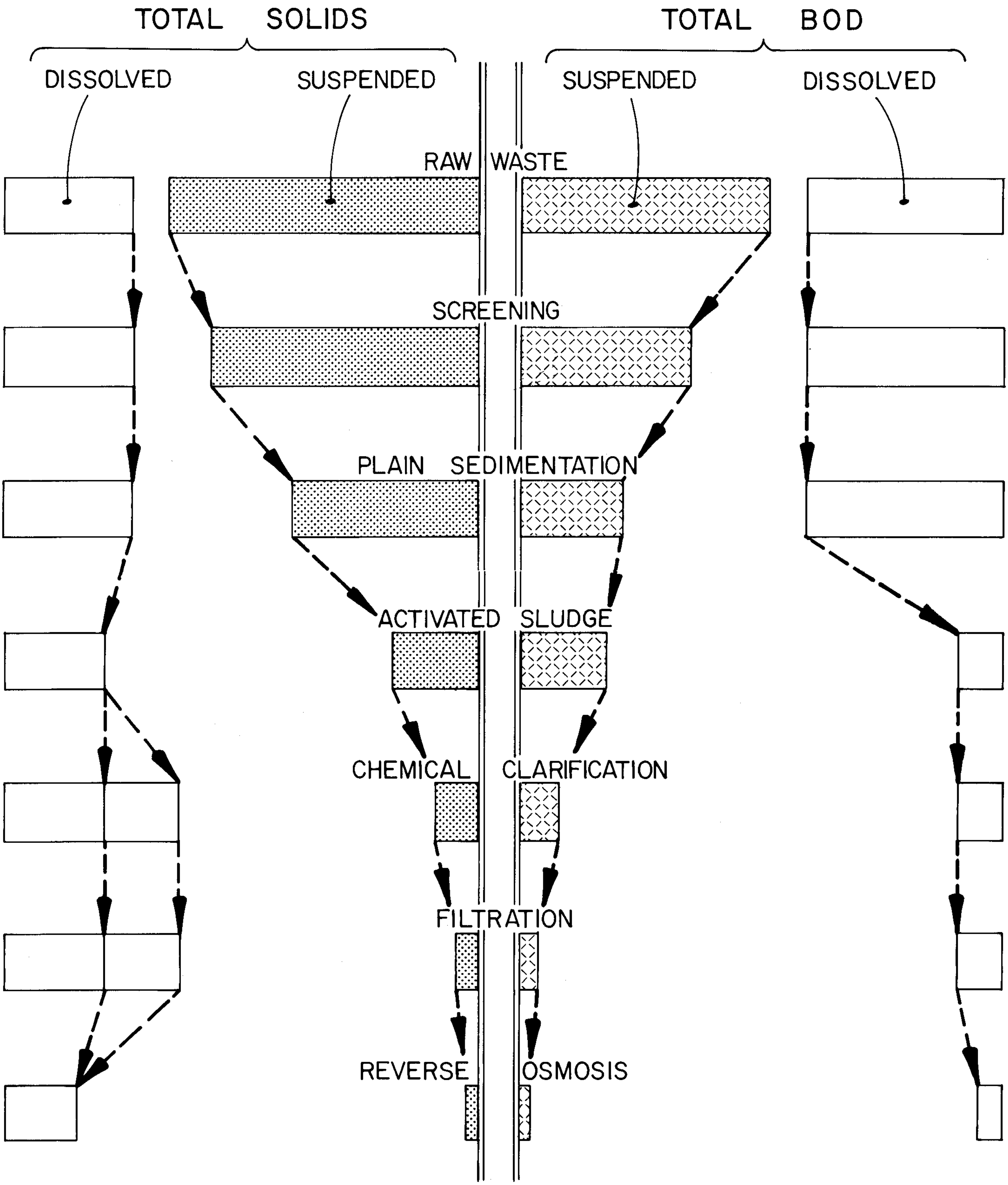

Figure 4.08. Effect of treatment on solids & BOD.

and aerated ponds, multiple aerated ponds, and anaerobic-aerobic ponds. The potato processors that were studied used primary clarifiers ahead of secondary treatment.[1,2] The 1983 guidelines are assumed to be met through the use of in-plant controls, the addition of more aerated lagoons or sand filters, and chlorination.

The effluent guidelines[3,4] assume that processors of all products other than apple, citrus, and potato products will meet the 1977 requirements with one of two kinds of secondary treatment: aerated ponds or activated sludge. The 1983 guidelines are assumed to be met by reducing the load on the treatment plants through in-plant processing changes, but large plants may have to add multi-media filtration.

Thus, for the future, primary treatment alone will probably be used only for discharge to some kind of land treatment system or for pretreatment. Primary treatment can be used as a first step in secondary treatment installations if the influent waste is high in settleable suspended solids (tomatoes, carrots, potatoes, etc.).

4.212 OTHER CONSIDERATIONS

Treatment may be needed to allow in-plant water reuse, ground water recharge, or to extend the life of a land treatment system. The State of California, for example, is setting standards for wastewater applied to land.

Wastewater used for irrigation has to meet the quality requirements outlined in Section 4.3 Treatment prior to agricultural use may be required. Minerals such as boron, sodium, and calcium play an important role in determining the feasibility of agricultural reuse. These constituents are seldom restricted in discharges to receiving waters.

Even if a food processing plant discharges to a public sewer system and has only a pretreatment requirement, the plant manager should understand the workings of the treatment processes. The opening of the processing season is usually a significant day for the operators of a public treatment plant. If a plant manager understands the effect his plant's wastewater has on the operation and performance of the public treatment plant, he is in a better position to communicate with the servicing agency staff and maintain good relations.

A basic understanding of the treatment processes will make it possible for food processors to judge the adequacy of proposed public systems which are intended to treat their processing wastes.

4.22 Primary Treatment

Primary treatment is used to remove floatable and settleable solids from wastewater. Solids removal can be by gravity (or by skimming, in the case of floatables) and may be assisted by chemicals (lime, alum, iron salts, or polymer) to make the particles settle faster. Removals can also be accomplished by mixing the wastewater with dissolved air and chemicals to make the solids float to the top.

Primary treatment of domestic sewage usually removes 40 to 60 percent of the influent suspended solids and 30 to 35 percent of the BOD. These removals are usually not achieved with food processing wastewaters. Typically, much of the BOD in these wastewaters is in a dissolved form that will not settle or float. Potato wastewater is an exception because 40 to 60 percent of BOD is removed with primary treatment.

Suspended solids reductions that are achievable in primary treatment vary widely with raw and finished products. Significant suspended solids reductions are attainable with primary treatment for products like potatoes, tomatoes, beets, or carrots, and very little reduction is achieved for products like corn, peas, peaches, or pears. Tomato processing wastewater is typically high in settleable solids from field soil, so primary treatment is effective. Primary treatment of potato wastewater can remove up to 90 percent of the suspended solids. Primary treatment is seldom used for apple juice wastewater because there are few settleable solids. The wastewater consists primarily of dissolved fruit sugars.

4.221 SEDIMENTATION

Primary treatment systems using gravity sedimentation are sized on the theoretical settling or falling rate of the slowest particles to be removed. This settling rate is expressed as gallons treated per day divided by the surface area of the clarifier (gpd/sf). Typical values are between 300 and 1,000 gpd/sf, which is equivalent to settling rates of 0.33 and 1.11 inches per minute, respectively (see Table 4.05). These settling rates can be determined by special laboratory tests. Clarifiers are usually at least 10 feet deep to allow for uneven flow distribution, sludge storage, and flow surges.

In addition to settling solids, primary clarifiers also thicken these solids. The solids loading on a clarifier affects the degree of sludge thickening. The solids loading is the total pounds of solids settled in a given time, usually one day, divided by the surface area of the clarifier. High solids loadings can also hinder the settling rate of solids. Typical values for solids loadings are given in Table 4.05.

Chemicals, such as lime, alum, iron salts, or polymers, may be added to gravity sedimentation tanks. This increases the rate of settling of the suspended particles by coagulating smaller particles together into larger particles. Because of fluctuations in chemical requirements, chemical coagulation systems can be extremely difficult to operate on food processing wastewaters, especially if consistently high removals are required.

Figure 4.09 is a cross section of a typical circular gravity clarifier. Common loadings for gravity clarifiers are given in Table 4.05.

4.222 FLOTATION

For certain wastewaters, dissolved air flotation clarifiers can be used effectively. Removal of suspended solids depends on the fine air bubbles that attach to each solids particle, providing buoyancy. The buoyant solids are then skimmed off after they rise and form a blanket, or float, on the top of the clarifier. Solids that settle are removed by either an auger or rake.

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1. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines for the Apple, Citrus, and Potato Processing Categories," March 1973.
2. *Federal Register,* "Effluent Guidelines and Standards, Apple, Citrus, and Potato Processing Categories," Vol. 39, No. 56, March 21, 1974.
3. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines. . .for the Fruits and Vegetables Point Source Category," October 1975.
4. *Federal Register,* "Effluent Guidelines and Standards, Fruits and Vegetables Category," Vol. 41, No. 75, April 16, 1976.

TABLE 4.05
PRIMARY TREATMENT DESIGN CRITERIA
FRUIT AND VEGETABLE WASTEWATERS

SEDIMENTATION	
CLARIFIER TYPE	Circular or rectangular with width equal to 1/4 to 1/3 of length.
BOTTOM SLOPE	1 - 2 inches per foot for light sludge. 3 - 4 for heavy sludge.
OVERFLOW RATE	
Common Municipal Waste	800 gallons/day/sq ft (gpd/sf)
Silt and Clay	300 gpd/sf
Lime Floc	900 - 1,000 gpd/sf
Alum Floc	600 gpd/sf
SIDE-WATER DEPTH	10 feet minimum. 12 feet best.
RAKE SPEEDS	Rectangular tanks: 2 - 4 fpm Circular tanks: 2 - 4 fpm at the tip, but should be 10 - 15 fpm for silt and clay.
SCUM REMOVAL	Should be on all clarifiers. Scum trough should be on downwind side of clarifier.
SOLIDS LOADING	10-30 lbs/sf/day for light organics. 80 - 100 lbs/sf/day for silt and clay.
SLUDGE PIPING	Preferably 6 inches diameter. Flow velocity should be 2 - 5 fps.
DISSOLVED AIR FLOTATION	
Overflow	1,000 - 5,000 gpd/sf
Air-to-solids ratio	0.01 - 0.1 lb air/lb solids
Recycle ratio	30 - 100 percent
Solids loading	0.3 - 1.3 lb/hr/sf
Pressure	50 - 60 psi

The most common type of air flotation is dissolved air flotation. A portion of the wastewater, usually the effluent, is pressurized and air is injected. When the air and solids mixture is released into the open tank, the air comes out of solution in small bubbles which attach to the solids.

Dissolved air flotation units must be designed empirically from pilot experiments for a given wastewater. Several criteria must be examined in the pilot studies. Chemical-dose requirements, hydraulic loading, solids loading, and the air-to-solids ratio are the criteria needed for a successful design.

Figure 4.10 shows a typical, rectangular, dissolved air flotation clarifier. This clarifier is equipped to remove solids from both the top and bottom. Common loadings in dissolved air flotation units are given in Table 4.05.

4.223 COMPLETE PRIMARY SYSTEMS

Figure 4.11 is a schematic of a complete primary system. In addition to the criteria that must be met in the design of the clarifier, it is vitally important that the sludge handling system be well matched to the wastewater treatment system.

The clarifier must be sized to store sludge until it can be accepted by the dewatering equipment (a vacuum filter or centrifuge). If the vacuum filter or centrifuge is undersized, the clarifier will fill with sludge. Some sludges become septic when stored. This usually causes a reduced dewaterability of the sludge and can also cause process failure and odors. Dewatering equipment is discussed in Section 4.5.

Systems having a dewatering unit must be designed to accept the recycled flow and solids from the unit as well as any wash or seal water used on the unit. These flows can be from 10 to 20 percent of the influent flow to the primary treatment system, and the solids from 5 to 20 percent of the influent solids.

Primary treatment systems operating on wastewater from certain crops, such as root vegetables and mechanically-harvested tomatoes, may have special problems with field soil (mud). Some clays and silts are thixotropic – they will solidify unless constantly agitated. If the sludge does solidify, it must be manually removed from the clarifier.

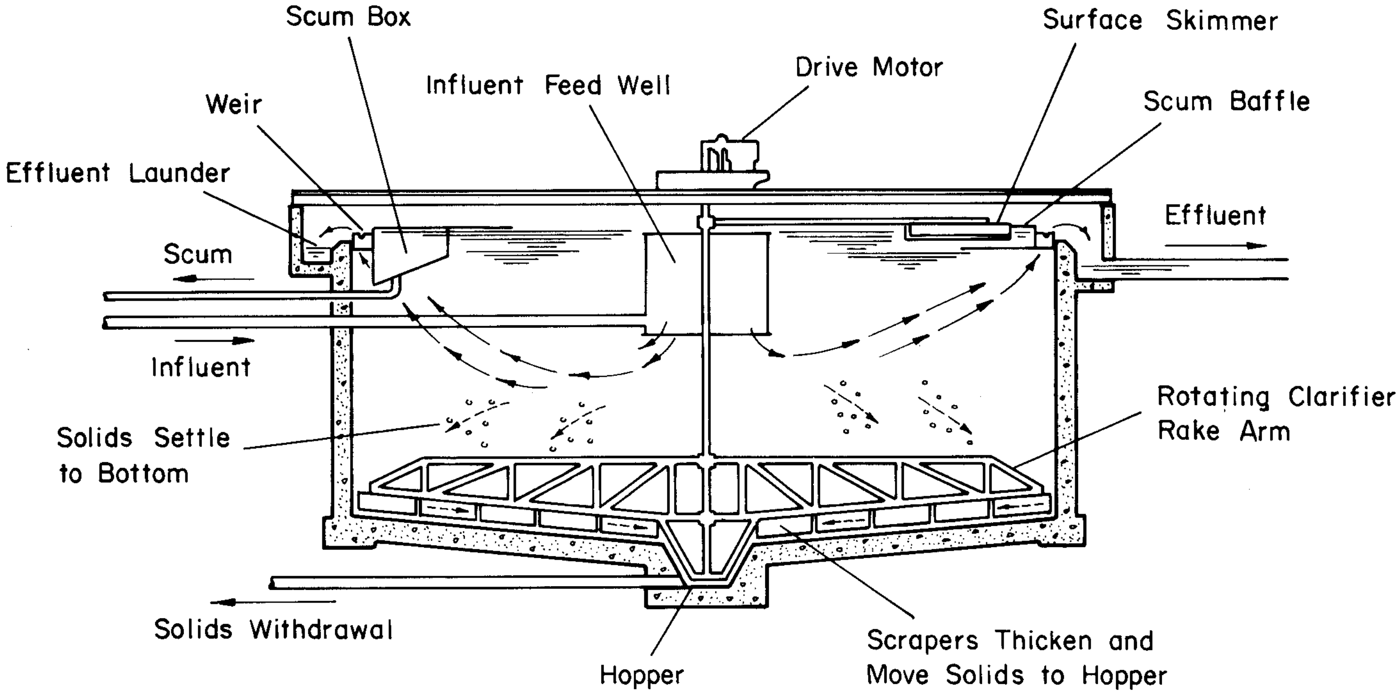

Figure 4.09. Clarifier

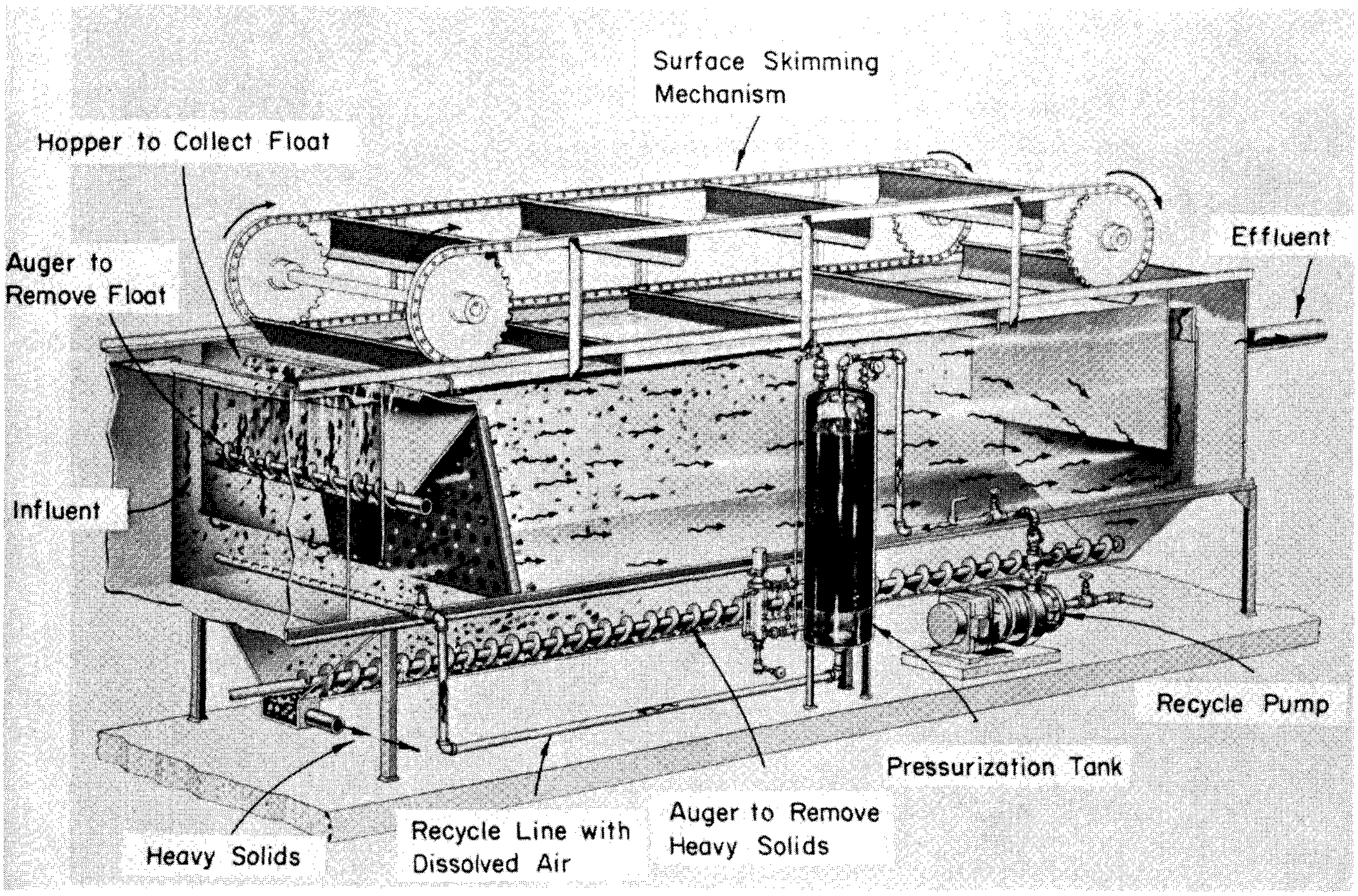

Figure 4.10. Dissolved-air flotation clarifier.

Most mud will settle and thicken in clarifiers to 30 to 40 percent total solids (by weight) depending on the fractions of sand, silt, and clay. At these concentrations the headloss in pump-suction pipelines is so great that pumping provisions must be made. The sludge pump should, preferably, be located beneath the clarifier near the center. Alternatively, dilution water can be added to the sludge at the center hopper of the clarifier.

4.23 Biological Secondary Treatment

4.231 INTRODUCTION

While primary treatment is used to remove settleable solids, secondary treatment removes soluble organic material (BOD) (Figure 4.08). Biological secondary treatment may be (1) aerobic, which means that the biochemical reactions are carried out in the presence of oxygen, or (2) anaerobic, in which case different biochemical reactions are carried out in the absence of oxygen.

4.232 PROCESS CHARACTERISTICS

Biological secondary treatment of wastewater essentially duplicates nature's processes in purifying a stream. Bacteria and other microorganisms play a vital role in both the natural and manmade treatment systems.

In natural waters bacteria (microscopic single cell plants) convert waste organic matter into more biological cells, water, and CO_2. To the bacteria the waste organic matter is food. Like all other living things the bacteria must have a reasonably balanced diet, requiring nitrogen, phosphorus, and numerous other elements in "micro" quantities. Unlike higher life forms most bacteria of interest in wastewater treatment can grow under conditions where oxygen is present (aerobic conditions) or where oxygen is absent (anaerobic conditions). Under aerobic conditions the general characteristics of the biochemical reactions are:

$$\text{Organic matter (BOD)} + \text{Bacteria} + O_2 + \text{nutrients}$$
$$(\text{N, P, etc.}) \rightarrow \text{More Bacteria} + CO_2 + H_2O$$

Protozoa and slightly higher animal life forms, such as rotifers and crustaceans, feed on bacteria and algae. Protozoa and all higher animal forms require oxygen (they are strict aerobes) for growth. Their population in the natural environment increases following an increase in the bacterial population. These tiny animals not only fill a valuable role in pollutant removal, they are also excellent indicator organisms in natural and manmade aerobic systems. A microscopic examination of either the natural microbiota or biological treatment system biota for protozoa, rotifer, and crustacean population size and the relative distribution of the individual species will tell much about the system's health. An excellent reference dealing with wastewater microbiology is McKinney.[1]

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[1] McKinney, R. E., *Microbiology for Sanitary Engineers*, McGraw-Hill, New York, 1962.

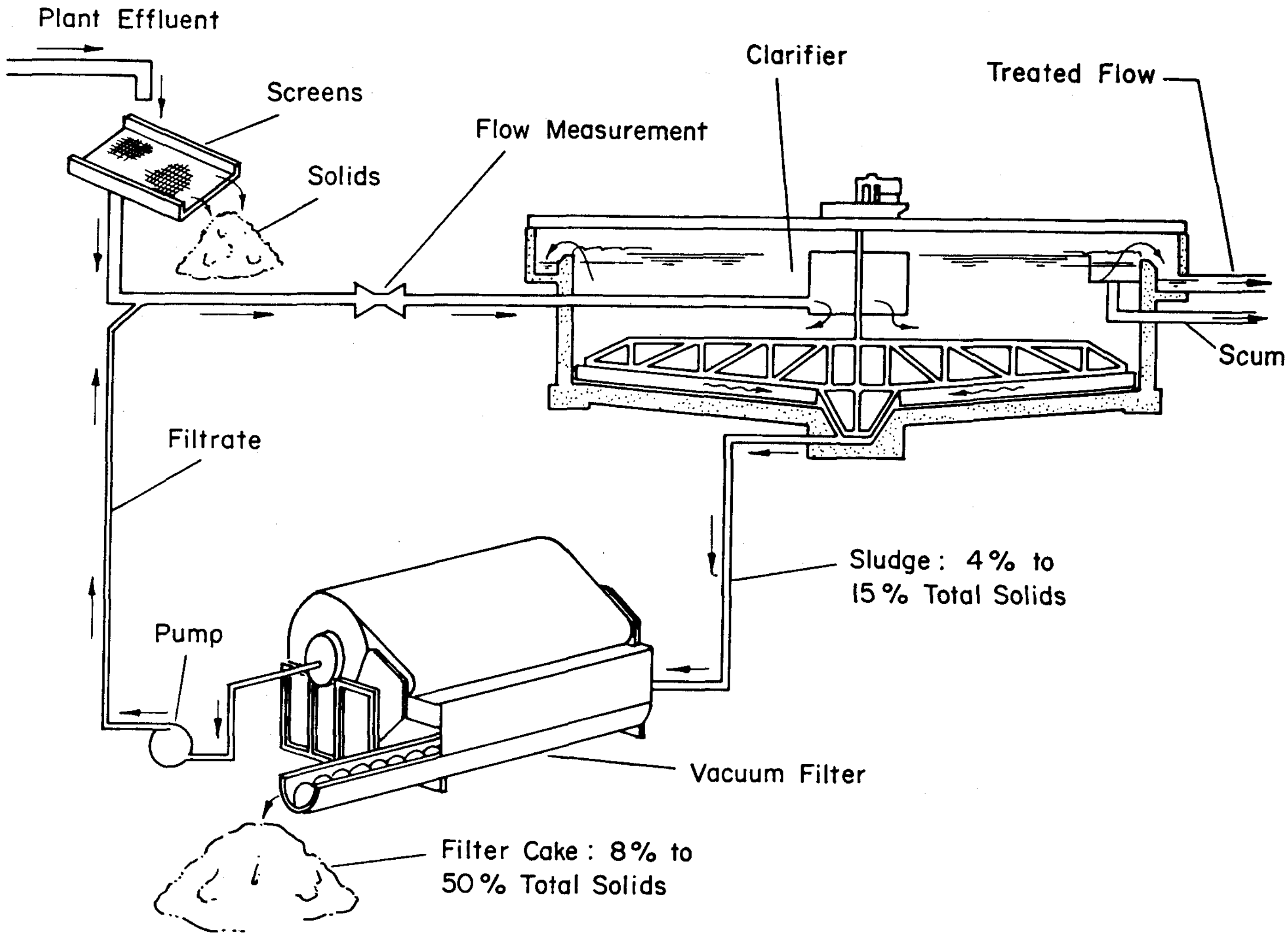

Figure 4.11. Primary treatment plant.

As previously indicated, many bacteria will grow under anaerobic conditions. Some bacteria (strict anaerobes) can only survive in the absence of oxygen. Those that can live and grow under either aerobic or anaerobic conditions are termed "facultative." Bacteria which must have free oxygen for growth are termed "strict aerobes." Again all protozoa and the higher animal forms are strict aerobes.

When bacteria in anaerobic systems are growing, the biochemical reaction is:

Organic Matter (BOD) + Bacteria + Nutrients (N, P, etc.) → More Bacteria + CO_2 + CH_4 (methane gas).

The anaerobic metabolism above is extremely inefficient when compared to aerobic metabolism. Note that methane gas is a product of anerobic metabolism. Most of the anerobic bacteria's food energy is "wasted" as methane. The bacteria in anaerobic systems must consume some five to ten times the organic matter (BOD) to gain a given increment in weight as do bacteria in aerobic systems. McCarty[1] reports the amount of bacterial growth under anaerobic conditions to vary considerably depending upon the nature of the organic matter consumed.

The natural environment is again referenced as a way of better understanding the interplay between many of the bacteria and other microorganisms which are beneficial to pollution control in both natural and manmade systems. Figure 4.12 depicts the impact of an organic pollutant discharge on a stream. The organic pollutant stimulates bacteria, using up oxygen. Fish are the first to die, followed by lower "animal" forms, including protozoa, requiring oxygen for life. Under anaerobic or septic conditions the stream supports little life higher than bacteria, both facultative and strict anaerobic types. Strict anaerobes may become established on the streambed, with facultative bacteria anaerobically metabolizing in the free flowing water above the streambed. Besides release of methane by the strict anaerobes and carbon dioxide by all bacteria in the septic portion of stream, the facultative bacteria will be consuming any oxygen which may exist in association with nitrogen (nitrate and nitrite) and sulfur (sulfate). Removal of this oxygen releases nitrogen gas and hydrogen sulfide. Release of hydrogen sulfide and other noxious gases results in the foul odor typically associated with grossly polluted streams, as well as the foul odor from many manmade anaerobic wastewater treatment systems and over-loaded systems designed to be aerobic.

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[1] McCarty, P. L., "Anaerobic Waste Treatment Fundamentals," *Public Works,* Vol. 95, Nos. 9-12, 1964.

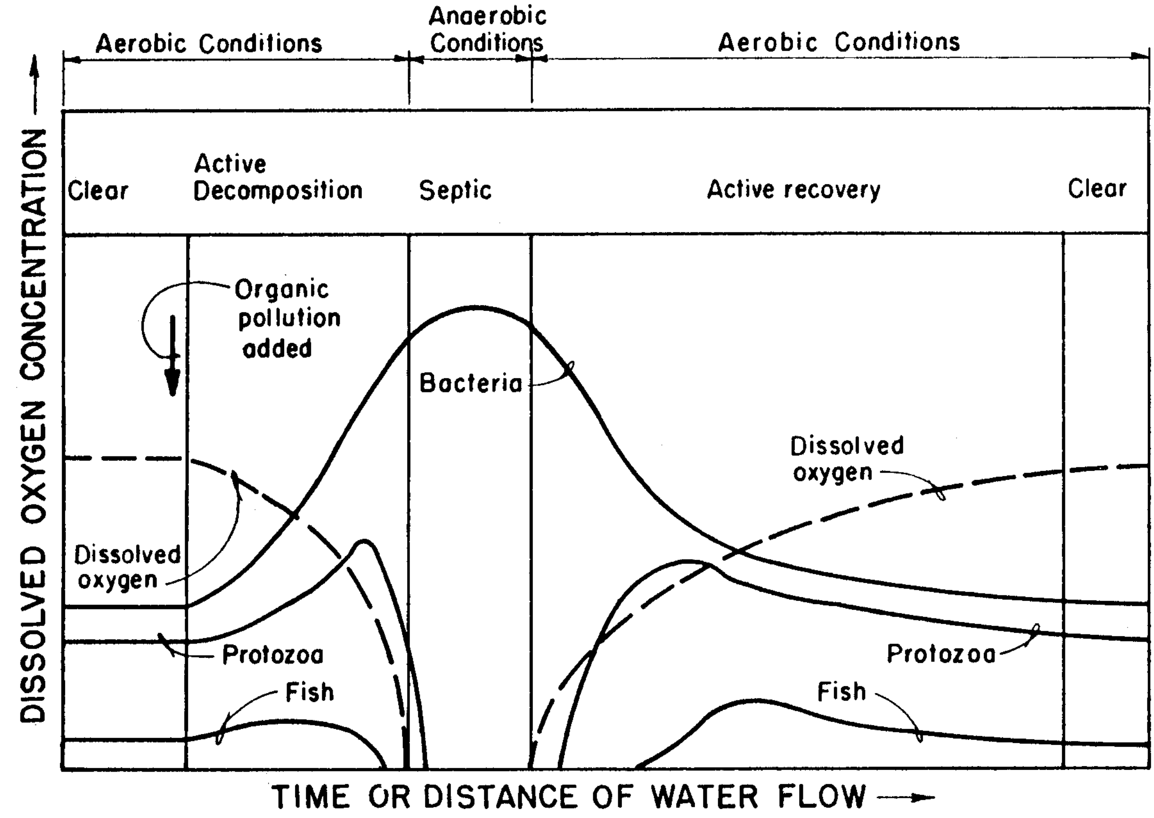

Figure 4.12. Nature's purification of wastewater in streams.

4.2321 BOD Removal and Sludge Production

Removal of organic pollutants (BOD) through biological secondary treatment is simply a matter of creating an environment in which bacteria and other microorganisms consume the organic pollutant as a food source. The pollutant is converted, as described in the previous equations, to products of microbial metabolism. The principal product of this metabolism with which we are concerned is the growth product – more bacteria and other microorganisms. While the pollutant may be removed, we are left with a fine suspension of microorganisms and associated debris. This suspension of solids must be removed by gravity sedimentation from the wastewater being treated before the secondary treatment job is complete. Microorganisms which escape secondary treatment with the treated effluent continue to respire, consuming available oxygen and reported as BOD and as suspended solids in effluent testing.

The effectiveness of BOD removal in aerobic biological secondary treatment is more directly related to the effectiveness of the suspended solids removal step than any other single factor. Microbial solids wasted from secondary biological treatment systems is termed "secondary sludge," discussed in more detail in Section 4.5. Net quantities of secondary sludge produced and requiring wastage are highly dependent upon the nature of the organic pollutant removed and type of treatment system. Some typical secondary sludge production values, per pound of pollutant removed, are listed in Table 4.06.

TABLE 4.06
SECONDARY SLUDGE QUANTITIES

System	Sludge Quantity* lb/lb BOD Removal
Anaerobic	0.03 to 0.15
Aerobic	
Activated Sludge	0.3 to 0.6
Activated Biological Filter (ABF)	0.2 to 0.5
Trickling Filters	0.1 to 0.3

*Assumes no significant quantity of nonbiodegradable suspended solids are contained in the secondary treatment plant feed.

Note the relatively low sludge production of anaerobic systems when compared to that of aerobic systems. In the anaerobic systems the principal factor in BOD removal is conversion of the pollutant to methane, not the effectiveness of the suspended solids removal process. In anaerobic treatment as much as 80 or 90 percent of the BOD reduction is actually conversion of the organic pollutant to methane gas which is, in turn, released from the wastewater.

While the importance of suspended solids removed in secondary treatment cannot be overstressed, the essence of every successful biological secondary treatment system is an adequate population of happy "desirable" microorganisms. As will be discussed later, designs or operations which do not provide the correct environmental conditions yield undesirable microbial populations – populations which do not settle or compact well in secondary clarifiers. The only effective means of ensuring growth of the "desirable" microorganisms and their consumption of the organic pollutant is through control of the aqueous environment. This means supply of proper and adequate nutrients and control of other environmental factors, as well as correct design of the physical wastewater treatment plant.

4.2322 Nutrient Requirements

In addition to the organic pollutants and oxygen, if aerobic, a biological system needs nutrients to maintain a healthy state. Microorganisms need about the same trace minerals as do humans. A significant deficiency in these nutrients can create a serious problem in wastewater treatment. The most common deficiencies in food processing wastewaters are nitrogen and phosphorus. The amount of these nutrients required for a given microorganism depends on its age; however, the amount of nutrients required for a treatment process depends both on the age of the microorganisms and the numbers of new microbes generated during the reduction of BOD. A BOD/nitrogen/phosphorus ratio of 100:5:1 is usually adequate. However, high-rate systems with no available nitrogen or phosphorus in the wastewater could require a ratio of 100:10:2. As seen in Table 4.07, most food processing wastewaters have a nutrient deficiency.

The values in Table 4.07 are taken from the EPA effluent guidelines report and presumably are developed from analyses for total nitrogen and phosphorus. Because most of the nitrogen found in food processing wastewater is in the form of insoluble organic nitrogen, it is not readily or fully available for microorganism use. Thus, a greater amount of supplemental nitrogen is needed than Table 4.07 would indicate.

Occasionally a wastewater will be deficient in nutrients other than, or in addition to, nitrogen and phosphorus. These other nutrients, generally termed "micro-nutrients," are required for microbial metabolism, although in only small quantities. The estimated requirements for micro-nutrients, given as a percentage of the nitrogen requirement, are as follows:

Sulfur	10% of the nitrogen requirement
Sodium	7% of the nitrogen requirement
Calcium	7% of the nitrogen requirement
Magnesium	5% of the nitrogen requirement
Potassium	3% of the nitrogen requirement
Iron	0.8% of the nitrogen requirement

These micro-nutrients need to be in the soluble state to be available. If a micro-nutrient deficiency is suspect, it is always well to check for these micro-nutrients in a system effluent sample from which solids have been removed via ≤.05 micron membrane filter. Soluble effluent micro-nutrient concentrations of less than 0.2 to 0.5 mg/1 may indicate micro-nutrient deficiency.

A shortage of any one nutrient can lead to a reduced ability of the microorganisms to remove the organic pollutant. An even more adverse impact of nutrient deficiency is, however, a shift away from the desirable single-cell microorganisms to a multicellular microbial growth, generally termed "filamentous microorganisms." These microbes do not settle or compact well in the sedimentation step associated with most secondary treatment processes. If the microorganisms become filamentous, they will tend to not settle but instead exit the system in the effluent, resulting in high effluent BOD and suspended solids readings and process failure. The filamentous growth condition is commonly termed "bulking sludge."

4.2323 Other Factors Affecting Efficiency

Several environmental factors are important to us here. They include pH, temperature, and toxicities.

TABLE 4.07
AVAILABLE NUTRIENTS
FRUIT AND VEGETABLE WASTEWATERS

COMMODITY	BOD/N/P RATIO	COMMODITY	BOD/N/P RATIO
Apricots	100/1.6/.23	Onions	100/3.1/.5
Artichokes	100/4.4/.8	Peaches	100/1.4/.3
Asparagus	100/6.5/1	Pears	100/1/.01
Beans	100/4.4/.8	Peas	100/6/.7
Beets	100/3.1/3.9	Pickles (avg sweet & dill)	100/1/1.2
Blueberries	100/.9/.1		
Broccoli	100/7.2/1	Pimentoes	100/2.8/.3
Brussels Sprouts	100/7.2/.7	Pineapples	100/.6/.1
Caneberries	100/1.8/.2	Plums	100/.6/.1
Carrots	100/2.3/.5	Potato Chips	100/1.1/.2
Cauliflower	100/6.8/.9	Potatoes	100/2.4/.4
Cherries	100/1.7/.2	Prunes	100/.7/.2
Corn	100/2.8/.5	Raisins	100/.7/.2
Cranberries	100/.7/.1	Rhubarb	100/3.0/.5
Dry Beans	100/5.4/.6	Sauerkraut	100/4/.5
Dehydrated onions	100/2.1/.004	Spinach	100/7.7/.6
Figs	100/1.3/.2	Squash	100/3.7/.7
Grapes	100/1.6/.1	Strawberries	100/1.6/.3
Jams & Jellies	100/.1/.01	Sweet Potatoes	100/1.3/.2
Lima Beans	100/5.4/.6	Tomatoes	100/4/.6
Mushrooms	100/7/1.9	Zucchini	100/5/.8
Okra	100/5/.6		
Olives	100/1.2/.1		

Source: EPA Effluent Guidelines Development Document[1]
Domestic waste ratio of 100/20/2

[1] Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines. . .for the Fruits and Vegetables Point Source Category," October 1975.

Most microorganisms grow best between the pH range of 6 to 9. Below pH 6 the hydrogen ion begins to exert a toxic effect; above pH 9 the hydroxyl ion becomes toxic. However, total lethality of bacteria does not occur until the pH is below 4.5 or above 10.5. Bacteria predominate in the normal pH range. Fungi will predominate over bacteria when the pH drops below 6, however, because of the ability of fungi to grow under acid pH conditions. Fungi grow in filamented form and are undesirable in most treatment plants.

Microbial metabolism responds to temperature much as do chemical reactions. The rate of metabolism, and hence growth, will double with each 10°C increase in temperature up to about 37°C-42°C where protein destruction begins in the common microorganisms. Thermophilic organisms exist which can grow readily up to 65°-70°C; however, these thermophilic organisms are seldom of interest in food processing wastewater treatment.

Temperature becomes a particular enemy when treating high strength food processing wastewaters under cold climatic conditions. Here special attention must be given to heat conservation and microorganism inventory in system design and operation. For a given effect, twice the weight of microorganisms must be actively growing in a given system at 10°C as at 20°C liquid temperature.

While the relative value of pH and temperature is important to all biological systems, the rate of variation in these parameters is particularly important to microorganisms in anaerobic systems. Temperature and pH changes here, even when remaining in the optimum range, should be made over several days' time. Sudden temperature and pH shocks to aerobic systems can also create process upset. Particular care should be maintained to avoid pH and temperature shocks to microorganisms recycled within a biological system. These shocks can occur when the microorganism recycle is combined with the wastewater entering the secondary treatment system whenever the wastewater varies greatly in either temperature or pH from that of the recycle.

Toxicity is seldom a problem in treatment of food processing wastewaters; however, it is well to remember the toxic potential of many metals and organics such as phenol and formaldehyde. Many heavy metals and other cations are necessary; however, in excess they interfere with microbial metabolism. Some cations of particular concern are copper, chromium, nickel, cadmium, zinc, lead, mercury, manganese, iron, silver, arsenic, and boron. Anaerobic systems are particularly sensitive to toxic effect and McCarty[1] has described these effects along with the safe toxic compound concentrations in feed to anaerobic systems.

4.233 ANAEROBIC SYSTEMS

Anaerobic wastewater treatment is not commonly used by food processors, but it is commonly used to digest sludges in public wastewater treatment plants. There are, however, two processes that are of use to food processors: anaerobic ponds and anaerobic filters.

4.2331 Ponds

Anaerobic ponds followed by some kind of aerobic process, like an aerated pond, are common in the meat packing industry and achieve high removals. Processors of potatoes, corn, apples, and some other products have also successfully used anaerobic ponds.

Anaerobic ponds are typically deep – 15 to 20 feet – and have a nominal retention time of 2 to 20 days. COD removals of 75 to 80 percent have been reported in the potato industry. Anaerobic processes often produce odorous gases. Consequently, if a natural floating cover of grease and solids does not form, an artificial cover may have to be constructed.

4.2332 Filters

A recent innovation is the anaerobic filter. Physically, the filters are covered tanks filled with large rock or other open media. The wastewater is passed through the tanks and the generated methane gas is collected. The methane gas can be used to heat the incoming wastewater or can be burned as a fuel. These filters have been used as a pretreatment device for a wheat starch wastewater. Removals of COD have been high – up to 80 percent – with a net retention time of 2 days in the tanks.

Once the anaerobic growth is fully developed and attached to the rock, the filter can be shut down for a period of months and restarted with only minor losses in efficiency, a substantial advantage to food processors.

Filters can be used as pretreatment units on selected high strength wastewaters before discharging to a public system.

4.234 AEROBIC SYSTEMS

Aerobic systems are the most common type used for wastewater treatment. Depending on how the treatment system is operated, the requirement for oxygen will vary from 0.5 to 1.14 times the amount of BOD removed. Methods of getting this oxygen to the microorganisms are discussed later.

The basic treatment unit is aerobic systems is a biological reactor (aerated basin, pond, trickling filter). This reactor provides an environment for the conversion of soluble organic material into suspended microorganisms. The subsequent unit is a secondary clarifier or pond where the microorganisms are allowed to settle. The settled microorganisms, or sludge, may be either returned to the biological reactor microbial mass (the mixed liquor), wasted from the system (waste sludge), or stored. As the result of biological growth, large volumes of organic solids are generated in secondary treatment processes. These solids are typically very wet (0.5 to 1.0 percent solids by weight), voluminous, and are difficult to dewater. In addition to the sludge resulting from biological growth, sludge also results from the removal of suspended solids that are not biodegraded.

Several different biological systems are used to provide secondary treatment. In all cases the secondary treatment units must provide an environment suitable for the growth of microorganisms. These treatment units depend on having enough oxygen to support aerobic metabolism of the organic matter. Aerobic microbial metabolism, if operating correctly, is practically odorless and is capable of high BOD removal (75 to 98 percent).

A summary of design factors for each process discussed is included in Table 4.08.

An artificial aeration (oxygen dissolution) system is required for nearly all aerobic treatment systems. These aera-

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[1] McCarty, P. L., "Anaerobic Waste Treatment Fundamentals," *Public Works,* Vol. 95, Nos. 9-12, 1964.

TABLE 4.08
SECONDARY TREATMENT DESIGN CRITERIA FRUIT AND VEGETABLE WASTEWATERS

COMPLETE MIX ACTIVATED SLUDGE	
AERATION BASIN	
Mixed Liquor Suspended Solids (MLSS)	2,000-4,000 mg/l
Food/Microorganism Ratio (F/M)	0.1-0.5 lb BOD removed/lb MLSS
Sludge Age (Days)	3-10 days
Aeration Time	8-48 hours, but controlled by sludge age, F/M, and MLSS concentration
Depth	10-20 feet
Aeration Type	Floating mechanical aerators or diffused aeration
Returned Sludge	25-100% of incoming plant flow
SECONDARY CLARIFIERS	Typical overflow rate is 400 gpd/sf. Solids or floor loading 10-20 lb/sf/day based on influent plus recycle flow. Most secondary clarifiers are circular.
HIGH-PURITY OXYGEN ACTIVATED SLUDGE	
AERATION BASIN	
Mixed Liquor Concentration (MLSS)	3,000-8,000 mg/l
Food/Microorganism Ratio (F/M)	0.5-0.7 lb BOD removed/lb MLSS
Sludge Age (Days)	6-10 days
Aeration Time	8-24 hours, but controlled by sludge age, F/M, and MLSS concentration
Depth	10-20 feet
Aeration Type	Mechanically agitated covered tanks fed high-purity oxygen
Returned Sludge	25-100% of incoming plant flow
SECONDARY CLARIFIERS	Same as conventional activated sludge except floor loading 20-40 lb/sf/day
AERATED PONDS	
Depth	7-15 feet
Hydraulic Retention Time	20-45 days
Oxygen Required	1.1-1.3 lb O_2/lb BOD applied
Mixing	Minimum—8-10 hp/mg Maximum—14-16 hp/mg
ACTIVATED BIOFILTER	
FILTER TOWER	
Height	12-22 feet
Configuration	Circular with rotating wastewater distributors, or rectangular with stationary distributor
Hydraulic Loading	1-2 gpm/sf of tower area including recycle
BOD Loading	0.15-0.3 lb BOD per cubic foot of filter media per day
Media Type	Redwood slats or various plastic shapes
AERATION BASIN	Same criteria as an activated sludge aeration basin. Assume that 40-60% of the influent BOD has been removed by the tower.
CLARIFIER	Same criteria as an activated sludge clarifier. Sludge can be returned to both the aeration basin and the filter tower. Floor loading 15-25 lb/sf/day
TRICKLING FILTER (High Rate)	
FILTER	
Depth	3-8 feet
Configuration	Circular with rotating distributor
Hydraulic Loadings	20-90 gallons/sf/day
BOD Loading	20-50 lbs BOD/1,000 cf
Recirculation	100-400% of influent flow
Media Type	Rock Media: 2-1/2-4 inches dia Plastic media now being used.
CLARIFIER	Overflow rate 400-600 gpd/sf Floor loading not critical
ROTATING BIOLOGICAL CONTACTOR	
CONTACTOR	Size to be determined by pilot testing
CLARIFIER	Overflow rate 400-600 gpd/sf Floor loading not critical

tion systems can be classified according to two approaches: (1) bubbling compressed air into the wastewater through the use of diffusers (diffused aeration), and (2) entrainment of oxygen in the wastewater through agitation of the surface (mechanical aeration).

Type of Aeration	Description
Mechanical surface	
Low speed	turbine gear box drive
High speed	propeller, direct drive from motor
Diffused air	
Fine bubble	socks, stones
Coarse bubble	holes in pipe
Sparged air	combines mechanical and diffused
Brush	rotating brush
Aspirator	Venturi aspirator
Others	small tubes with slits, spiral static diffuser

Blowers in diffused-air systems compress air to about 8 psi. The compressed air then enters the wastewater through diffusers mounted close to the bottom of the aeration basin. Many methods exist to diffuse air into solution, but for all of these the efficiency of oxygen transfer from the diffused air to the wastewater is only about 7 percent. Diffusers clog easily from particles in the wastewater or from deposits that build up on the diffuser pores. Diffusers should be mounted so they can be easily removed for cleaning. As a rule, to maintain complete mixing, 20 to 30 cfm (cubic feet per minute) should be applied to each 1,000 cubic feet of basin volume. Diffused-air systems deliver about 1.0 pound of oxygen per horsepower-hour at field conditions at sea level.

A typical mechanical aerator is shown on Figure 4.13. These aerators may be either rigidly mounted in a tank, or installed with floats so they can rise and fall with the water level, as illustrated. Mechanical aerators typically deliver 1.5 to 2 pounds of oxygen per horsepower-hour at field conditions at sea level. The amount of power required to maintain complete mixing with these units is 1/2 to 1-1/2 horsepower per 1,000 cubic feet of basin volume, depending upon basin configuration and MLSS concentration.

Aeration equipment is rated at the following standard conditions:

> 20 degrees Centigrade, zero dissolved oxygen in water being aerated, transfer rates and solubilities for tap water (clean water), at sea level.

Actual design operating conditions will likely be:

> 4 degrees to 30 degrees Centigrade, 2.0 to 3.0 mg/l dissolved oxygen, reduced transfer rates and solubility for wastewater above sea level.

The actual net transfer under field conditions for all types of aeration systems will range from 35 to 60 percent of the rated condition.

4.2341 Stabilization Ponds

Stabilization ponds are large, usually 3 to 6 feet deep, and retain the wastewater for a period of 60 days or longer. Oxygen needed for biological action comes primarily from the

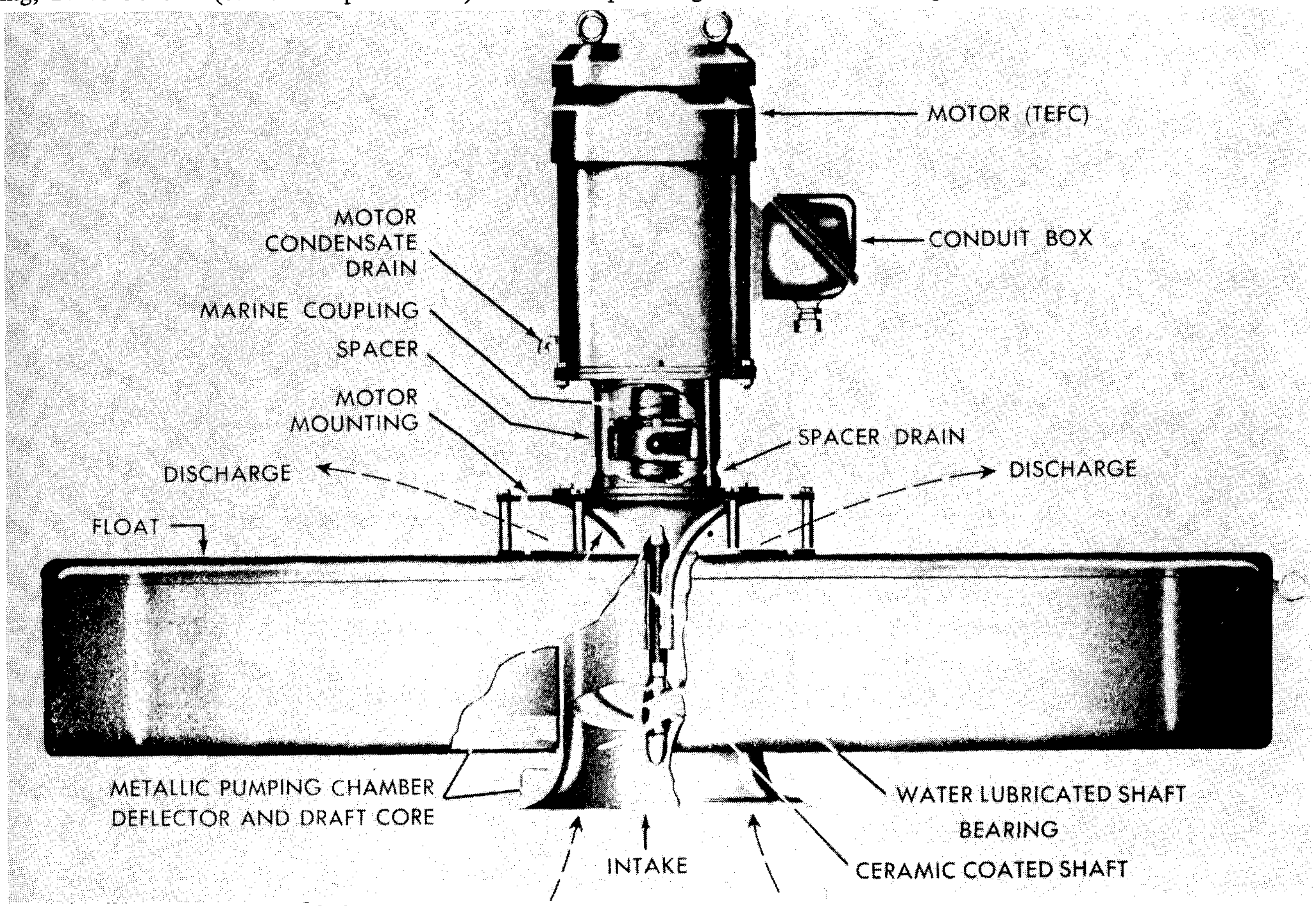


Figure 4.13. Floating mechanical aerator.

action of photosynthetic algae, although some oxygenation occurs as a result of the contact between the pond surface and the atmosphere. Depending on the degree of treatment desired, stabilization ponds may be designed to be operated in a variety of ways, including series and parallel operations; in some cases, treatment may include tertiary ponds for algae removal prior to effluent discharge.

Because of the high strength of food processing wastewaters, BOD loadings determine the necessary size of the ponds. The loading should be kept at 20 to 40 pounds BOD per acre per day. A lagoon area of about 300 acres would be required for a 1 mgd flow with a BOD of 1,000 mg/l.

Stabilization ponds can cause problems that result in their being abandoned:

1. Growth of algae may result in high effluent suspended solids and BOD.
2. Odors may occur, especially during startup.

Several algae removal systems are under study and some under construction; however, there is no full-scale, long-term operating experience.

4.2342 Aerated Lagoons

Aerated lagoons are similar to stabilization ponds, except the oxygen is artificially added either by compressed-air diffusion or by mechanical agitation (Figure 4.13). Supplemental aeration allows the pond volume to be greatly decreased and the depth increased (to 12 feet or more with special provisions for mixing), thus reducing surface area and heat loss. The biological life in an aerated lagoon will contain limited numbers of algae, but will be otherwise similar to that found in activated sludge.

Adequate mixing must be provided in aerated lagoons to distribute oxygen; this will require 8 to 16 horsepower per million gallons. However, the mixing should not be over 16 horsepower per million gallons or sludge will be suspended. The exact limits depend on the type of aeration as well as the depth and configuration of the lagoon. At least 0.2 pound of sludge is produced for each pound of BOD removed. These solids will accumulate and must be eventually removed or they will discharge in the effluent. Lagoons in series are often used for solids separation.

Table 4.09 presents cost of an aerated lagoon for a 1-million-gallon-per-day wastewater flow. In addition to the assumptions given in the table, the following should be noted:

- Lagoon depth is 10 feet.
- Inside slope is 3:1, outside 2:1.
- Mechanical aerators: 12 at 40 hp each and one at 20 hp; all moored to the bottom.
- Total land for both lagoons is 11 to 12 acres.

TABLE 4.09

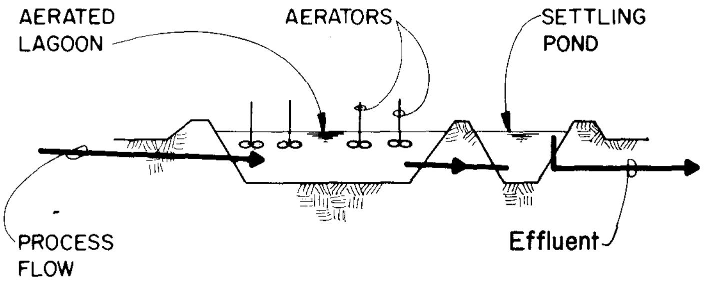
COST SUMMARY AERATED LAGOON SYSTEM

CRITERIA

• FLOW:	I MGD AVERAGE 2 MGD PEAK
• BOD:	1000 mg/l
• TSS:	1000 mg/l
• pH:	4.5
• SEASON:	90 DAYS
• AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- BOTH AERATED LAGOON AND SETTLING POND ARE LINED EARTHEN BASINS
- 30-DAY DETENTION TIME IN AERATED LAGOON
- 400 GPD/SF OVERFLOW RATE IN SETTLING POND
- NO NUTRIENT ADDITION
- EXCAVATION & DISPOSAL COST AT $4/cy
- POWER COST AT 2 CENTS/KW-HR

COSTS

CAPITAL	OPERATION AND MAINTENANCE	
$517,700	LABOR	4500/yr
	POWER (500 hp)	16,000/yr
	TOTAL	$20,500/yr

AMORTIZED CAPITAL PLUS O & M	$112,100/yr
UNIT COST	125¢/1000gal

- Material used in dike construction comes from the lagoon excavation.

4.2343 Activated Sludge

In activated sludge wastewater is discharged into an aerated basin. The presence of abundant organic matter, nutrients, and oxygen is favorable to sustaining a large concentration of microorganisms. Ordinarily, dissolved-oxygen levels are kept at 2 to 3 mg/l. The combination of the wastewater flow and microorganisms is called mixed liquor. The mixed liquor flows from the aeration basin to clarifiers where the microorganisms settle from the liquid. The settled microorganisms (activated sludge) are returned to the aeration tank to maintain the mixed-liquor suspended solids (MLSS) concentration.

The excess microorganisms produced and nonbiodegraded materials removed in secondary treatment are wasted from the system (waste activated sludge or secondary sludge). A schematic of an activated sludge plant is given on Figure 4.14. Design criteria for activated sludge processes are given in Table 4.08. Figures 4.15 and 4.16 are photographs of activated sludge plants treating potato wastewaters.

An operational problem with activated sludge plants is bulking. Sludge bulking is the inability of the activated sludge to settle or thicken in the secondary clarifier. This occurs commonly in plants treating wastewater containing a high percentage of carbohydrates (corn, apples, etc.) because of the formation of filamentous, or stringy, bacteria (see also Sections 4.2322 and 4.2323 for other causes and effects of filamentous microorganisms in wastewater treatment). Unless carefully designed and operated, plants will develop filamentous growth and consequently not perform efficiently. Control of bulking conditions, once they have occurred, is discussed in Section 4.66.

There are many variations of the activated sludge process. These variations are generally confined to (1) the means of introducing the wastewater feed into the aeration basin and (2) the means of introducing oxygen to and its distribution within the aeration basin. These differences, while seemingly minor, do yield differing process results when applied in the field.

Section 4.2322 discussed the need for nutrients in activated sludge systems to minimize the tendency toward growth of filamentous (bulking) microorganisms. Remember that with a shift of the system microbial population well toward the filamentous form, the secondary clarifier fails, resulting in high effluent BOD suspended solids readings and, finally, process failure. Of equal or greater importance than adequate nutrients to avoid sludge bulking is maintaining adequate dissolved oxygen at all points within an aeration basin, with particular concern to any portion of the basin with a higher than average influent organic feed concentration.

The definition of adequate dissolved oxygen in aeration basins is continuously being revised upward. In theory as little as 0.5 mg/l is adequate for aerobic metabolism. Since microorganisms in activated sludge systems tend to exist in micro-floc forms, microbes near the center of these micro-flocs tend to see a far lower dissolved oxygen level than those on the very surface of a micro-floc or those in a dispersed state. Whenever micro-environments begin to exist within the system at dissolved oxygen levels at 0 to 0.5 mg/l, the filamentous microorganisms are favored and system efficiency is threatened. Design of air activated sludge systems to maintain a minimum measured dissolved oxygen concentration of 2 to 3 mg/l at any location in the basin is now recommended to avoid existence of the low dissolved oxygen microenvironments. High-purity oxygen (HPO) systems operate at even higher dissolved oxygen levels, 6 to 15 mg/l. Evidence is mounting that the higher the dissolved oxygen carried, the less the tendency toward filamentous microorganisms.

With the foregoing in mind, a brief discussion of the following activated sludge system variations is in order:

- Plug Flow
- Step Aeration
- Complete Mix
- Contact Stabilization
- High-Purity Oxygen (HPO)

The original activated sludge system was developed in a plug flow configuration. This configuration uses a long, narrow aeration basin, generally employing diffused aeration. The feed and recycle is introduced at one end, with aeration being ap-

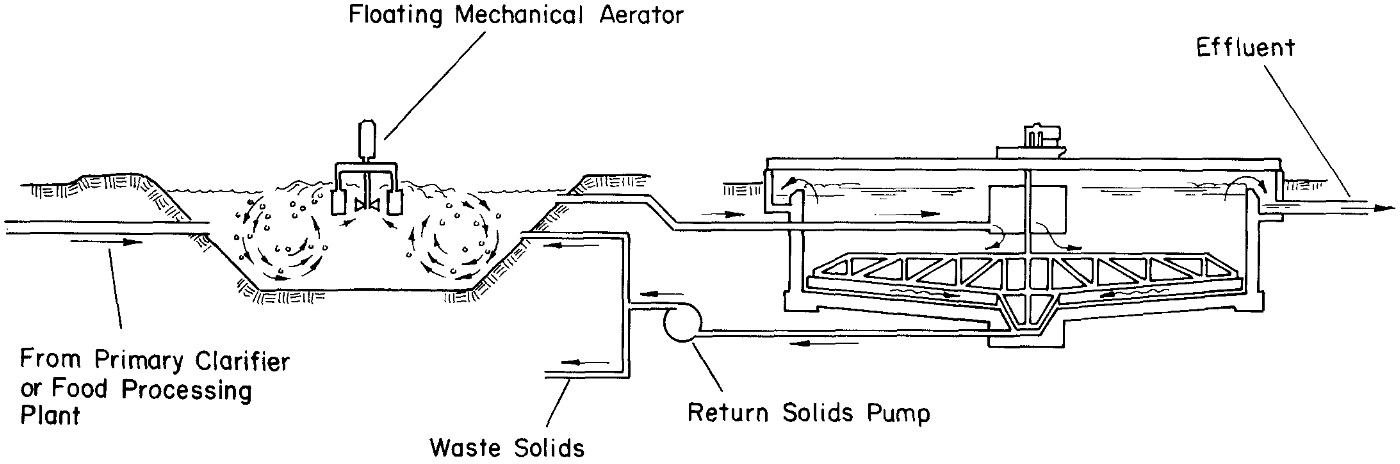


Figure 4.14. Activated sludge plant diagram.

Figure 4.15. Activiated sludge plant.

plied uniformly through the full basin length. Demand for oxygen is extremely high at the head of the basin such that when the feed is a food processing wastewater, the demand cannot be met with most conventional aeration systems. As a result, bulking (filamentous microorganism) occurs. Conventional plug flow activated sludge should only be of historical interest to food processors. Figure 4.17 schematically depicts the plug flow system.

Step-aeration was developed to overcome problems associated with oxygen demand at the basin head exceeding aeration capacity. Figure 4.17 shows the step feed feature and oxygen demand in relation to dissolved oxygen. The means of influent feeding is the only difference between the conventional plug flow activated sludge should–only be of historical interest to food processors. Figure 4.17 schematically depicts most food processing wastewaters than is plug flow.

A complete mix activated sludge configuration is generally preferred for high strength carbohydrate food processing wastewaters. As the name indicates, the aeration basin contents are completely mixed. The feed and recycle are immediately dispersed throughout the basin upon entry. There is no oxygen demand variation within the basin, and the oxygen supply is similarly uniform. Aeration may be either by mechanical or diffused means. Basin configuration (tending toward square or circular) better accommodates the more inexpensive and efficient mechanical aeration equipment than does that of the conventional plug flow or step-aeration configurations. Another advantage of the complete mix design is it ability to receive and absorb shock organic and toxic loads without the process upset which would occur if the same load were applied to other air activated sludge systems. Design criteria for a complete mix activated sludge system are presented in Table 4.08.

The contact stabilization design (see Figure 4.18) is of interest more for its differing configuration than for its applicability to most food processing wastewaters. Indeed, this system would not be recommended for consideration unless the wastewater flow were large, relatively low in BOD (less than 250 mg/l), and with a minority of the BOD in soluble form. The contact stabilization system takes advantage of the ability of microorganisms to gorge themselves on food, storing most of this both inside the cell (absorption) and outside the cell (adsorption). The detention time under contact aeration is short (30 minutes plus, depending on wastewater). Following clarification, the solids are "reaerated" for several hours such that the total sludge age is comparable to that of other activated sludge variations. The contact stabilization process is not known to produce an effluent as high in quality as that produced by the complete mix or step-aeration systems.

The activated sludge process using high-purity oxygen (HPO) is a recent and significant innovation. This system uses covered multistage (3 to 5 stages – see Figure 4.18) aeration basins into which oxygen-rich gas is fed. Oxygen utilization is approximately 90 percent. Oxygen concentration varies from above 90 percent in the inlet gas to 30-50 percent in the exhaust or vent gas. Mechanical mixers project through the roof

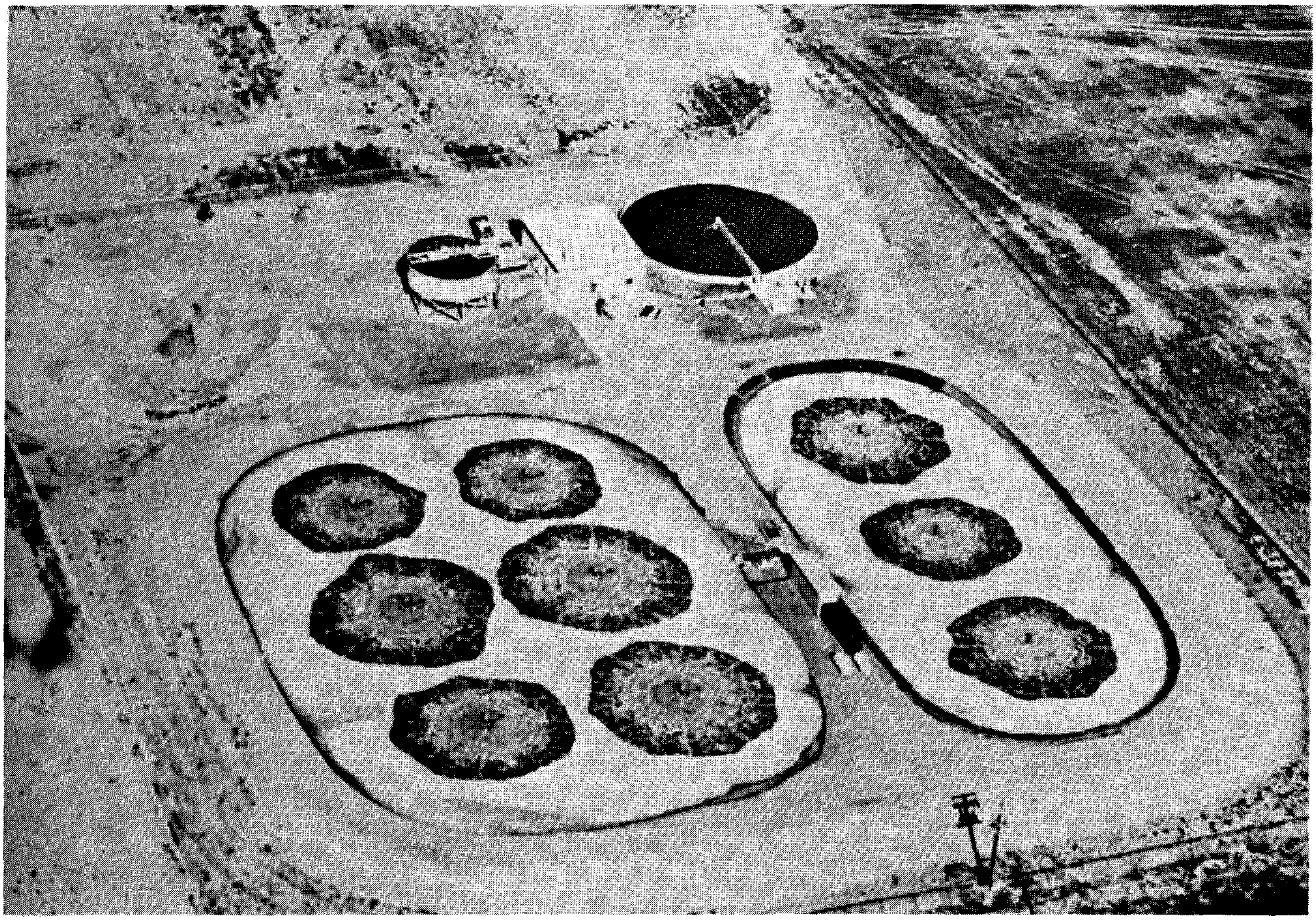


Figure 4.16. Activated sludge plant.

to mix the basin contents and entrain the oxygen. Dissolved oxygen concentrations can be maintained at high levels (6 to 15 mg/l versus 2 to 3 mg/l in conventional plants) in the wastewater flow. The basin effluent is clarified in standard secondary clarifiers and sludge is returned to the first-stage aeration cell. Excess sludge is wasted as it is in any other activated sludge plant.

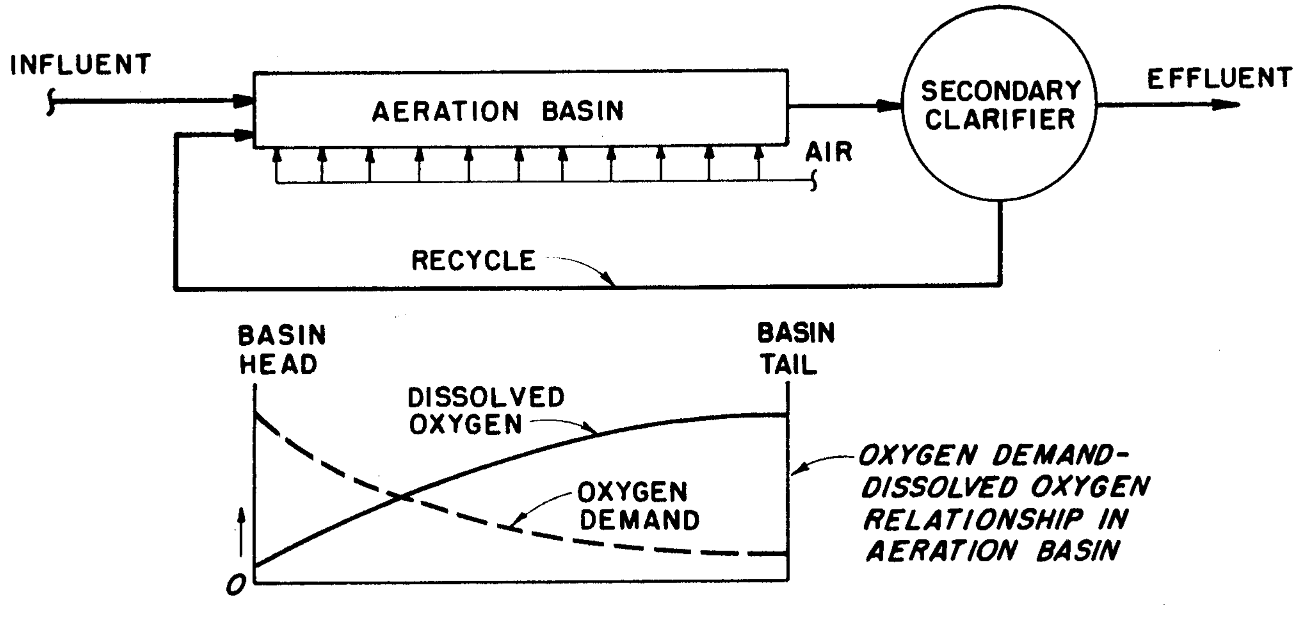
Current knowledge of food processing wastewater and the high-purity oxygen activated sludge process suggests that when compared with more conventional activated sludge systems, this modified process results in the following advantages:

- A sludge more settleable in secondary clarifiers, resulting in lower secondary effluent suspended solids and BOD levels. This has been observed in treatment of other high-strength carbohydrate wastewaters. We believe it is related to the high dissolved oxygen concentration within the system as discussed previously.
- Retention of wastewater heat necessary for effective treatment in cold climates.
- Less land area.

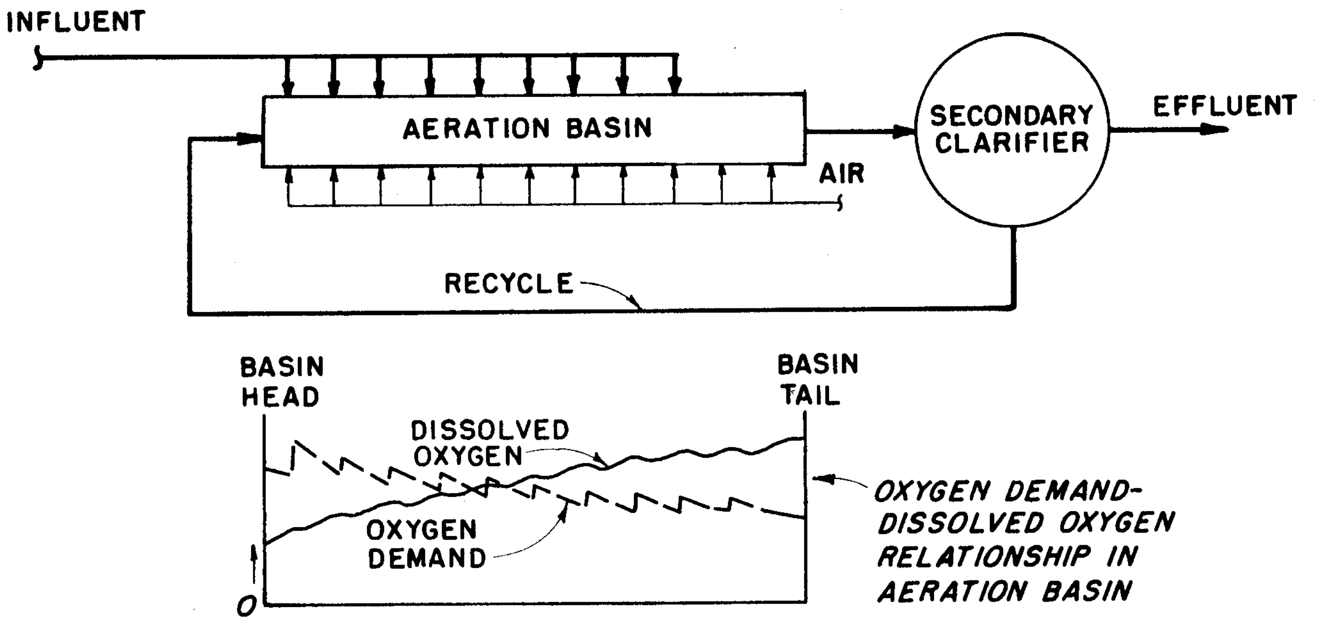
The capital cost of a high-purity oxygen system is usually greater than conventional systems, but it should be considered where the need for biological secondary treatment is indicated. Commonly used design criteria for HPO processes are given in Table 4.08.

Tables 4.10 and 4.11 give cost estimates for an activated sludge plant (1.0 mgd) both with and without sludge digestion and dewatering. In addition to the assumptions listed in the tables, the following should be noted:

- System configuration: Complete mix
- Activated sludge food to microorganism ratio (F/M) is 0.2, where:
  F = pounds BOD to influent per day, and
  M = pounds of mixed liquor/suspended solids under aeration
- Aeration basin sludge age: 6.5 days
- Aeration basin mechanical aerators: 10 at 50 hp each
- Two 40-foot diameter clarifiers
- Area requirements for activated sludge alone: about 2 acres
- Area requirements with digestion, dewatering: about 3 acres
- Aerobic digester sludge age: 15 days
- Two gravity dewatering units for waste sludge concentration
- Raw-waste activated sludge to truck: 95,000 gal/day at 0.8 percent solids
- Digested, dewatered, waste activated sludge to truck: 35 cubic yards/day at 9 percent solids
- Small building for motor control center and pumps
- Small building to house dewatering units



PLUG FLOW SYSTEM



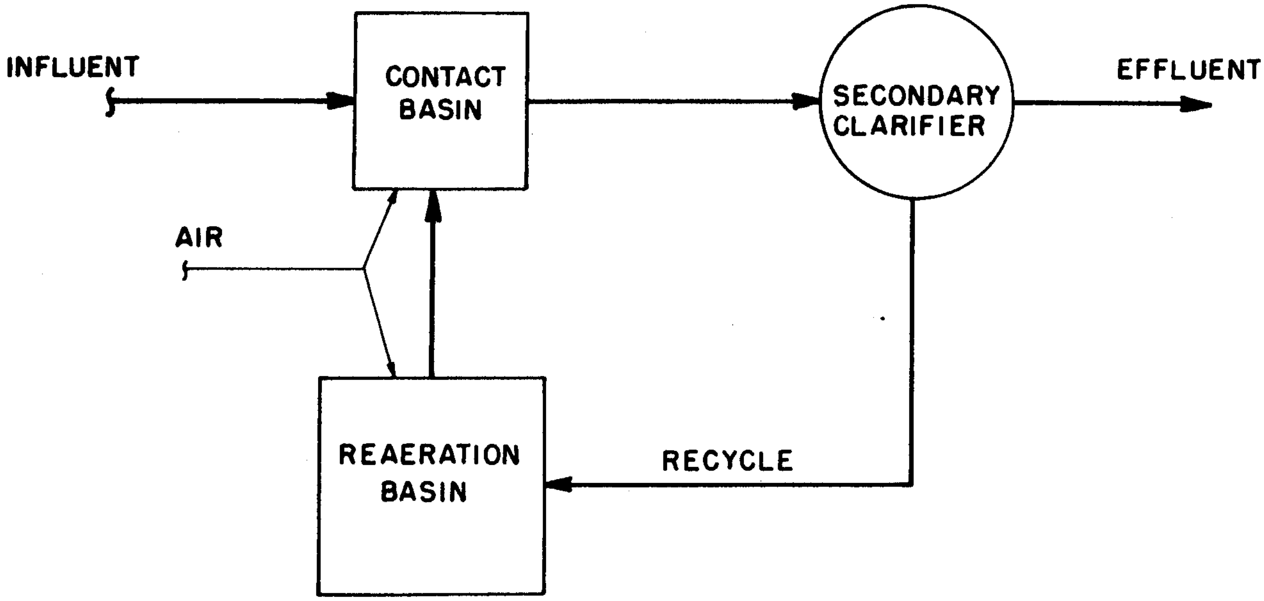
STEP-AERATION SYSTEM

Figure 4.17. Plug flow and step-aeration activated sludge.

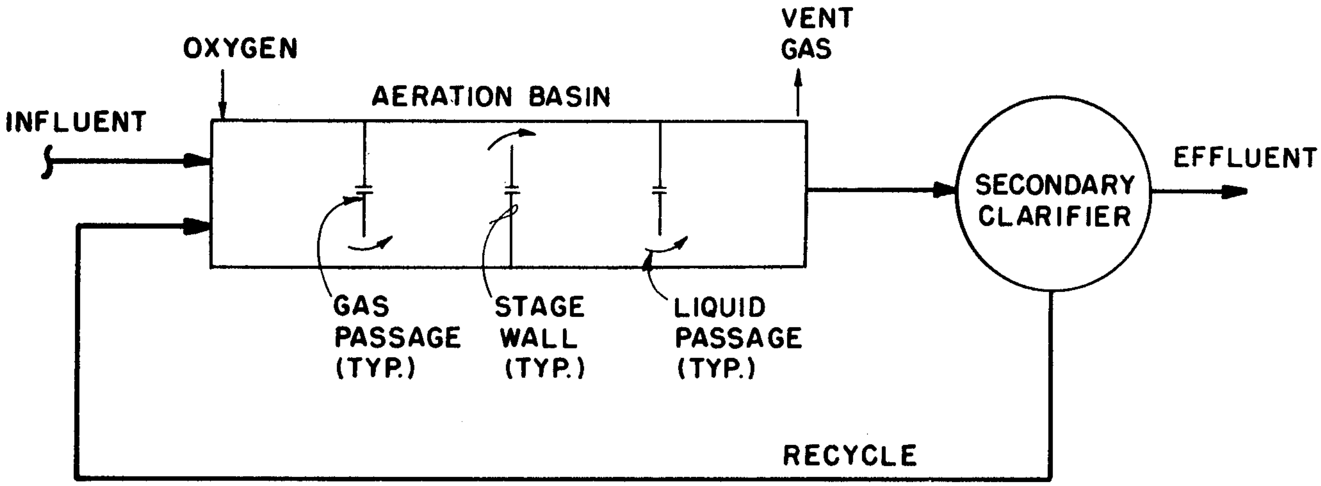
4.2344 Activated Biological Filter (ABF)

Activated bio-filtration (ABF) was developed in recent years to take maximum advantage of artificial filter media characteristics. Plastic and redwood biological filter media have high void-to-total-volume ratios and high surface-to-total-volume ratios. These characteristics make high organic loadings possible.

In the original ABF system, secondary clarifier underflow is combined with the secondary plant influent and pumped to the bio-filter. Microorganisms grow on the filter media and in the wastewater flow. Portions of the bacterial mass continuously slough from the media, join the bacteria growing in the wastewater, and settle out in the secondary clarifier.



CONTACT STABILIZATION SYSTEM



HIGH-PURITY OXYGEN SYSTEM

Figure 4.18. Contact stabilization and high-purity oxygen activated sludge.

Most of the microbial mass settled in the secondary clarifier is returned to the filter influent to maintain a high concentration of microbes in the flow through the filter. The flow scheme has the appearance of activated sludge, giving rise to the process name, activated bio-filtration.

A recent modification of the ABF process has been the insertion of an activated sludge aeration tank between the ABF tower and the final clarifier. The effluent from the tower is sent through the aeration basin for further treatment. The aeration basin is designed to assimilate 40 to 60 percent of the organic loading to the tower. The return sludge from the final clarifier is usually returned to the tower.

The ABF-activated sludge process has shown great promise in successfully treating high carbohydrate wastewaters (potatoes) without developing the sludge bulking problems of activated sludge. The process is also resistant to shock loadings.

Figure 4.19 shows a circular ABF tower operating on combined domestic and potato wastewater. The towers (about 20 feet high) may also be square or rectangular. Figure 4.20 is a schematic of the ABF-activated sludge process. Design criteria for ABF-activated sludge plants are given in Table 4.08.

4.2345 Rotating Biological Contactor (RBC)

This system has many large diameter, lightweight disks

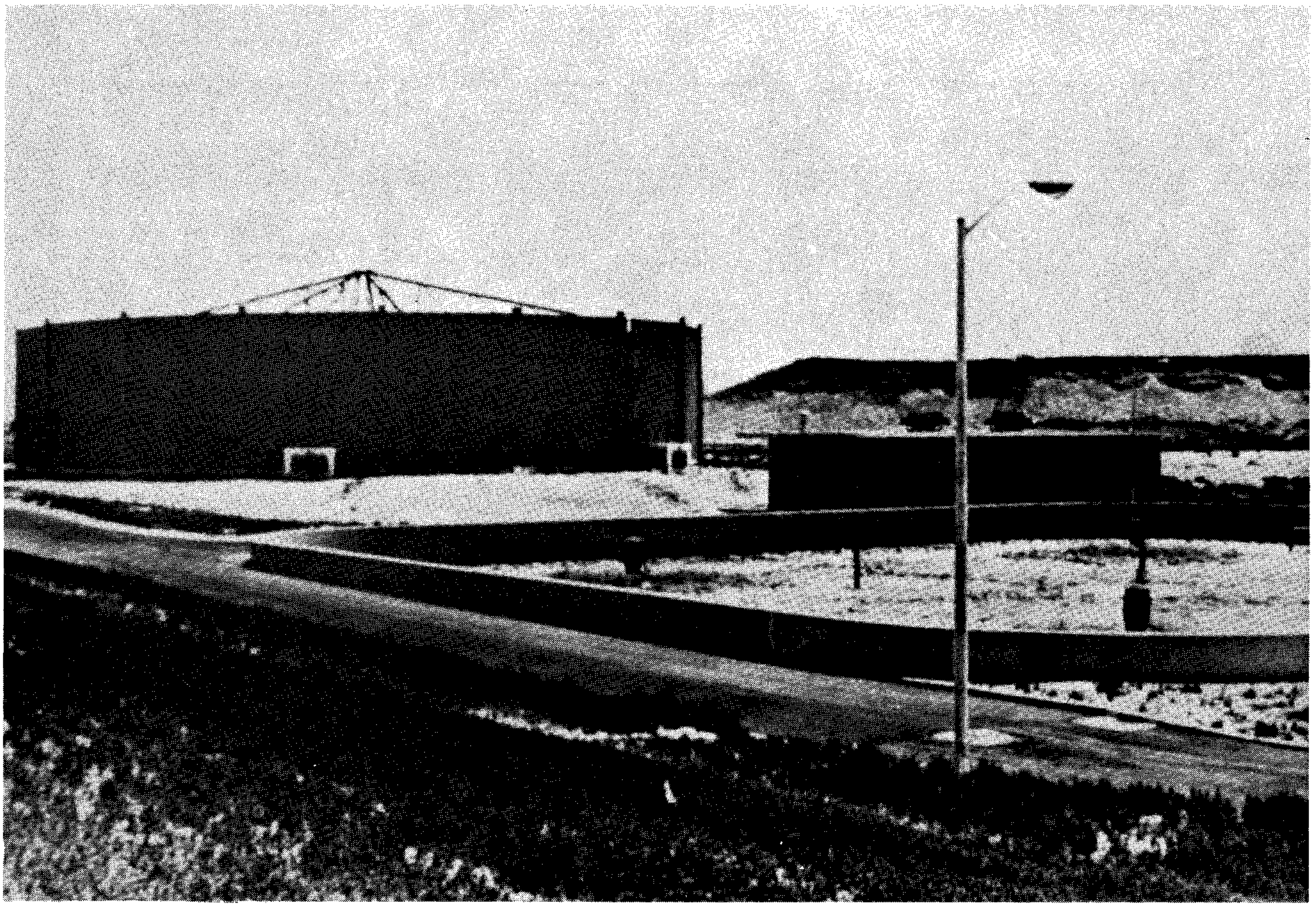


Figure 4.19. Activated biological filter tower.

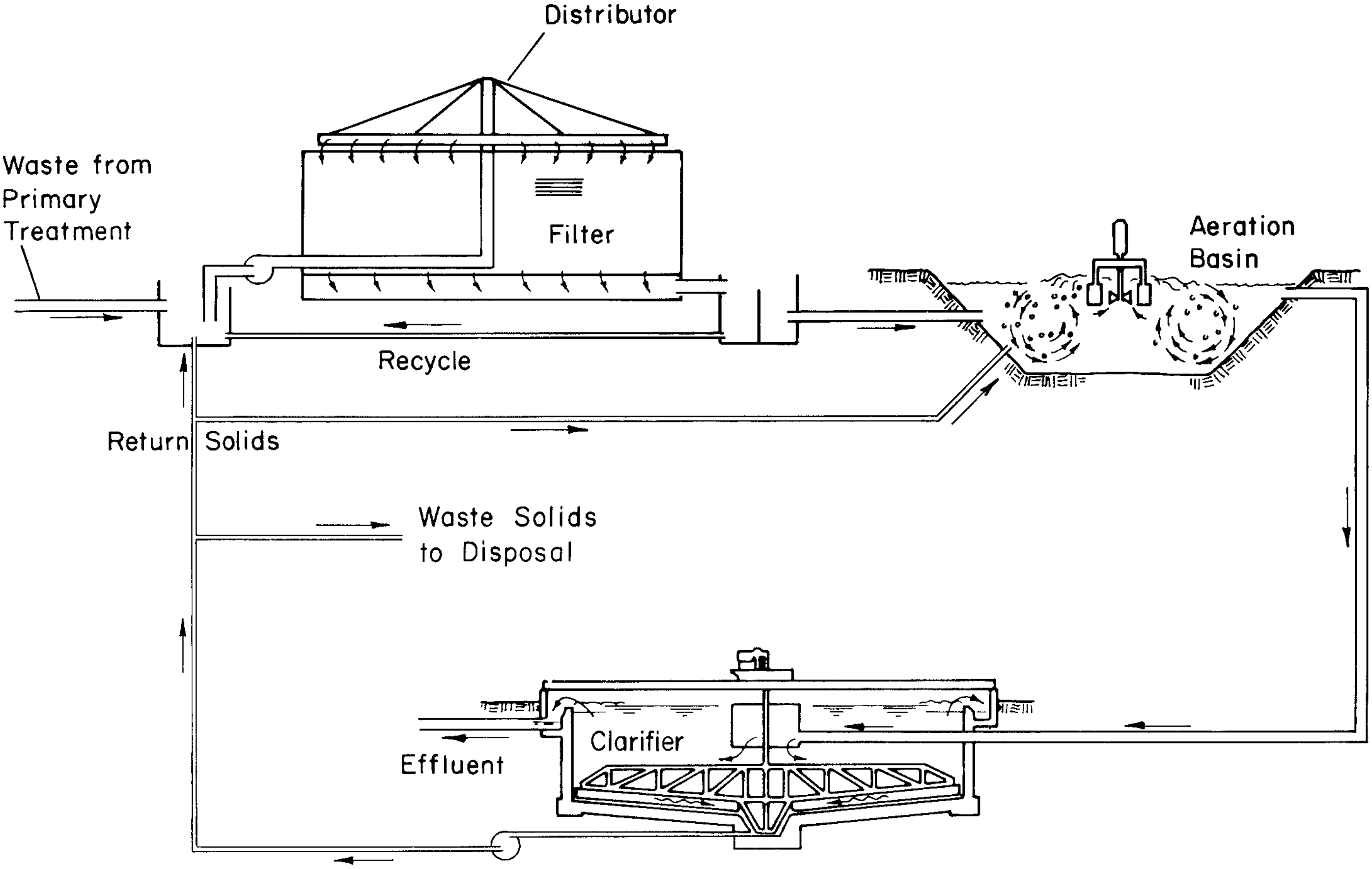


Figure 4.20. Activated biological filter; activated sludge plant.

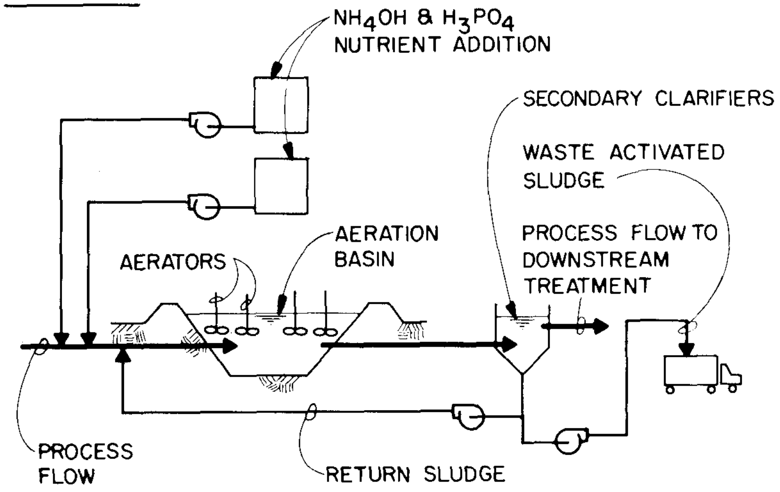
TABLE 4.10
COST SUMMARY ACTIVATED SLUDGE SYSTEM

CRITERIA

• FLOW:	1 MGD AVERAGE 2 MGD PEAK
• BOD:	1000 mg/l
• TSS:	1000 mg/l
• pH:	4.5
• SEASON:	90 DAYS
• AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- LINED EARTHEN AERATION BASIN WITH 2-DAY DETENTION TIME
- TWO CONVENTIONAL SECONDARY CLARIFIERS WITH 400 GPD/SF OVERFLOW RATE
- COST OF NH_4OH AT $184/TON (100% BASIS) COST OF H_3PO_4 AT $0.215/lb SOL'N.
- POWER COST AT 2 CENTS/KW-HR
- W.A.S. DISPOSAL COST AT 1.5 CENTS/gal FOR 20-MILE HAUL

COSTS

CAPITAL
$645,000

OPERATION AND MAINTENANCE	
LABOR	$5000/yr
NITROGEN	2900/yr
PHOSPHOROUS	5000/yr
POWER (500 H.P.)	16,000/yr
WASTE SLUDGE DISPOSAL	130,000/yr
MISCELLANEOUS	16,100/yr
TOTAL	$175,000/yr

AMORTIZED CAPITAL PLUS O&M	$289,150/yr
UNIT COST	321 ¢/1000 gal.

mounted on a horizontal shaft in a semicircular shaped tank. Ths disks are rotated slowly with the lower half of their surfaces submerged in the wastewater. Microorganisms grow on the disk surfaces and in the tank. In rotating, the disks carry a film of wastewater into the air where it absorbs oxygen. The mixing created by the disk rotation also transfers oxygen to the tank contents. Shearing forces cause excess bacterial growth to slough from the disks and into the wastewater. The sloughed solids flow out with the treated wastewater to the secondary clarifier for separation and disposal.

Rotating biological contactors have been successfully applied to domestic and some industrial wastewater. Operation is simple and power requirements are low, but the capital costs of the disks are high. Some structural problems associated with maintaining shaft-disk integrity also exist. Purchase of a unit of given design should be preceded with the vendor's demonstration that units of like design and service have performed properly over a considerable period of time. Before this sytem is applied to treatment of food processing wastewaters, pilot plant testing and economic analysis should be undertaken to answer questions about (1) effect of wastewater pH, (2) effect of wastewater strength, (3) temperature effects, (4) BOD and suspended solids removal efficiencies related to BOD and suspended solids unit loadings, and (5) capital and total costs compared to alternative systems.

4.2346 Trickling Filters

One of the oldest biological treatment systems is the trickling filter. Typically, the filter is a 6-foot bed of 2-1/2-inch to 4-inch rock over which the wastewater is distributed. Atmospheric oxygen moves naturally through the void spaces in the rock. In the environment thus created, microbial slimes (consisting mainly of bacteria) flourish and colonize on the rock surfaces. As the wastewater trickles over the surface of the growths, organic matter is removed. As the growths become more and more concentrated, their attachment to the media surface is weakened and they are washed from the filter. The solids are then removed by sedimentation as in other high-rate processes. See Figure 4.21 for a diagram of this process.

There are a number of variations of the biological filter process, depending on the wastewater loadings applied to the filters, the arrangement of the units, and the number of filters employed.

Trickling filters are very stable and easier to operate than activated sludge plants. Removals of BOD seldom exceed 80 percent, and the effluent contains a higher level of suspended solids than effluent from the activated sludge process. For this

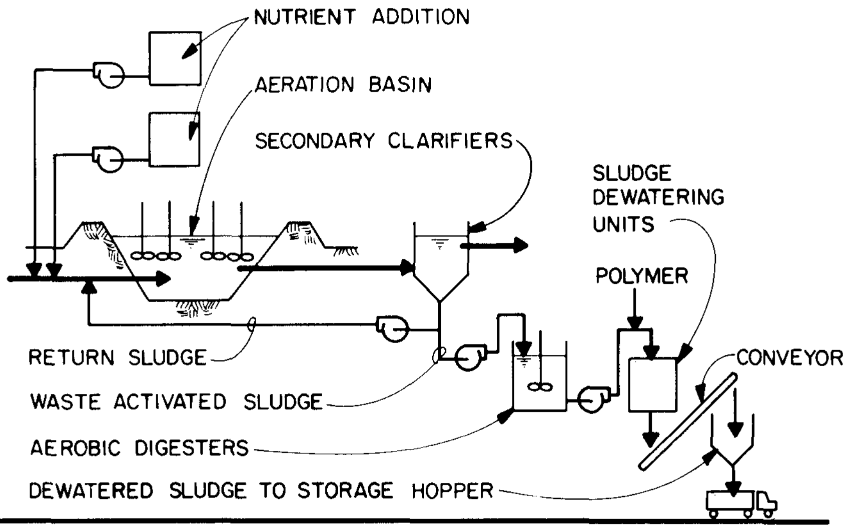
TABLE 4.11
COST SUMMARY ACTIVATED SLUDGE WITH AEROBIC DIGESTION AND DEWATERING

CRITERIA

• FLOW:	1 MGD AVERAGE 2 MGD PEAK
• BOD:	1000 mg/l
• TSS:	1000 mg/l
• pH:	4.5
• SEASON:	90 DAYS
• AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- SEE ASSUMPTIONS FOR ACTIVATED SLUDGE SYSTEM (TABLE III-6A)
- DEWATERED SLUDGE TRUCKING COSTS AT $3.70/TON DRY SOLIDS/MILE
- POLYMER ADDITION AT 6 lb/TON SOLIDS
- POLYMER COST AT $2.25/lb
- UNIT DEWATERING RATE AT 1000 GPH FOR DIGESTED SLUDGE

COSTS

CAPITAL	OPERATION AND MAINTENANCE	
$1,115,000	LABOR	$6300/yr
	NITROGEN	2900/yr
	PHOSPHOROUS	5000/yr
	POLYMER FOR SLUDGE	3000/yr
	POWER (575 H.P.)	18,500/yr
	DEWATERED SLUDGE DISPOSAL	17,000/yr
	MISCELLANEOUS	5800/yr
	TOTAL	$58,500/yr
AMORTIZED CAPITAL PLUS O&M		$255,850/yr
UNIT COST		284¢/1000gal

reason, no new trickling filter plants are now being designed to meet the new EPA requirements. Common design parameters for trickling filters are given in Table 4.08.

4.24 Tertiary (Advanced) Treatment

With the exception of two or three rapid-sand filter installations, tertiary treatment is not being practiced by the food processing industry[1,2]. We do not expect that tertiary treatment will be necessary to meet EPA regulations, but it may be required in some cases where more stringent requirements have been imposed. Only those processes with the greatest possible applicability are discussed here (Table 4.12). These processes are: chemical precipitation, filtration, carbon adsorption, ion exchange, and reverse osmosis. In the discussion we assume that any advanced process will be treating effluent from a secondary treatment plant.

4.241 CHEMICAL PRECIPITATION AND SEDIMENTATION

The primary application for this step as a tertiary process is the removal of suspended solids escaping secondary treatment. The process involves the use of a coagulant to form a metal precipitate which "sweeps" out other suspended colloidal matter while settling. The coagulants commonly used are lime, alum, ferric chloride, and other iron salts. Polymers are sometimes used as a primary coagulant, but most often as an aid.

Simplified chemical reactions illustrating the action of these coagulants are given below:

Lime

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3(\downarrow) + 2H_2O$$

Alum

$$Al_2(SO_4)_3 + 6HCO_3^- \rightarrow 3SO_4^= + 2Al(OH)_3(\downarrow) + 6CO_2$$

Ferric Chloride

$$FeCl_3 + 3H_2O \rightarrow Fe(OH)_3(\downarrow) + 3H^+ + 3Cl^-$$

Note: ($\downarrow$) indicates a solid material or precipitate that settles out.

The overflow rate on the chemical clarifier can be from 500 to 2,000 gpd/sf, depending on the coagulant used. Expected

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[1] Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines for the Apple, Citrus, and Potato Processing Categories," March 1973.

[2] *Federal Register,* "Effluent Guidelines and Standards, Apple, Citrus, and Potato Processing Categories," Vol. 39, No. 56, March 21, 1974.

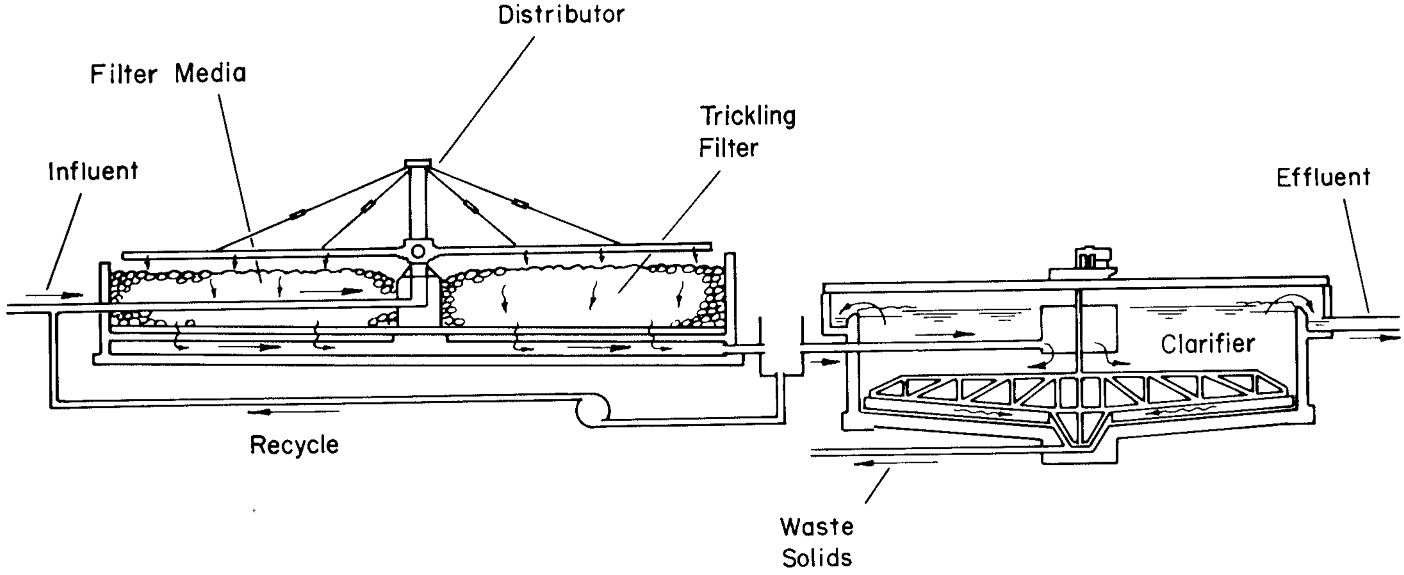


Figure 4.21. Trickling filter plant.

solids concentration in the sludge varies from 3 to 7 percent.

If lime is used as a coagulant, the floc is very dense and settles easily. The use of alum increases sulfates in the water, and the floc is more difficult to settle and dewater than lime. The use of ferric chloride increases the chloride concentration in the water and can cause low pH problems. Chemical precipitation, however, is the most efficient way to prevent deterioration of effluent during biological plant upsets.

4.242 FILTRATION

Filtration reduces suspended solids of colloidal size – those that will not settle out. Historically, a single media was used with a filtration rate of 0.05 to 0.13 gpm/sf. This has been termed "slow-sand filtration." Rapid-sand filtration, in use now, uses a filtration rate of 1 to 5 gpm/sf. In addition to single-media filters originally used, dual- and tri-media filters are also used.

Filters may be classified by five parameters: (1) direction of flow, (2) type of media, (3) flow rate, (4) gravity or pressure, and (5) cleaning method.

TABLE 4.12
TERTIARY TREATMENT APPLICATIONS

PROCESS	POLLUTANT TO BE REMOVED				
	COD	BOD	Suspended Solids	Dissolved Salts	Refractory Organics
Carbon Adsorption	X	X			X
Chemical Precipitation	X	X	X	X	Will remove some refractory compounds
Filtration	X	X	X	X	X
Ion Exchange	X	X		X	X
Reverse Osmosis	X	X		X	X

The filters used most successfully on wastewater today are downflow filters using dual- or tri-media. A filtration rate of 2-1/2 to 5 gpm/sf is common. Cleaning is by hydraulic backwash, commonly at a rate of 15 gpm/sf. This backwash may be preceded by air backwash and assisted by surface wash. Often a filtration aid, such as polymer or alum, is added to the feed to strengthen floc and improve solids removal. Figure 4.22 shows a small package pressure mixed-media filter installation.

Single-media filters ordinarily remove only 70 percent of the influent solids under ideal conditions. Seventy-five to ninety percent of the headloss occurs in the first inch of this media, so it is easy to see that filtration is really a surface phenomenon. In addition, single-media filters tend to "blind-off" at the surface, reducing filter run time and thus necessitating more frequent backwashing.

Mixed-media (dual- or tri-media) filters generally give longer runs and better removals. The media is slightly more expensive. The idea of mixed-media is to provide a constant gradation of pore size in the filter, from coarse on the surface to fine on the bottom. The gradation in pore size allows filtration and storage of solids throughout the depth of the bed, as opposed to a single-media bed in which filtration takes place in the top portion.

As a rule filters cannot be used when the influent suspended solids exceeds 100 mg/l or when the size distribution of solids fluctuates widely. It is also usually uneconomical to use filters if the required backwash volume exceeds 10 percent of the incoming flow. A better choice would be a chemical clarifier.

A primary key to successful operation of filters is adequate backwash. There must be provision to break up surface slime and caking.

Table 4.13 gives a cost estimate for mixed-media filtration of 1 mgd of secondary effluent. We assumed that filtration was a workable option for additional removal of suspended solids. This is not always the case. Secondary effluent sus-

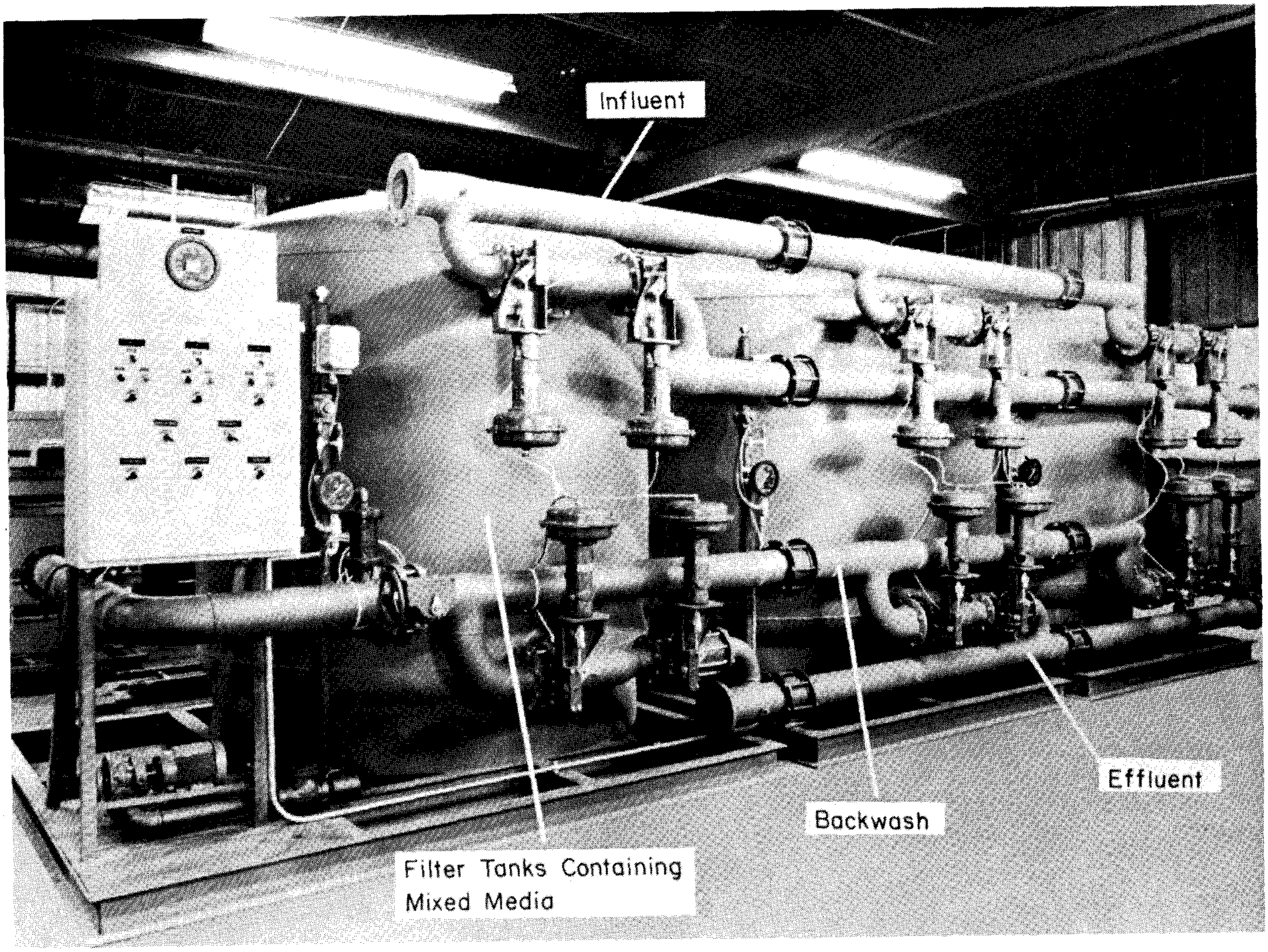


Figure 4.22. Pressure filter.

pended solids may be high enough to "blind off" filters after a short run time (less than 6 hours). When this happens, filter backwash volumes become so large that the secondary plant capacity must be significantly increased to handle the backwash return flow.

In addition to those shown in Table 4.13, the following assumptions in the development of the estimates should be noted:

- 2 horizontal pressure filters
- Filter rate: 2.5 gpm/sf
- 150,000 gal lined earthen surge pond ahead of filters
- 60,000 gal concrete clearwell
- 60,000 gal backwash return surge pond
- Polymer aid dose: 1 mg/l

4.243 CARBON ADSORPTION

Carbon adsorption removes refractory organic compounds like those causing taste and odor (tannins, lignins, and ethers). It also removes residual COD, BOD, insecticides, herbicides, and related components. However, few tests have been run with activated carbon treating food processing wastewater.

Carbon adsorption can be done using either granular or powdered activated carbon. Powdered carbon still has many problems, not the least of which is its recovery for reuse. However, the technology of granular activated carbon in columnar beds is well developed.

The influent to a granular carbon process must be low in BOD, COD, and suspended solids. The effluent from carbon adsorption can go to ion exchange, or reverse osmosis, and/or disinfection.

A criterion for design is to use upflow expanded bed columns with a contact time of 20 minutes. The hydraulic rate should be between 6 and 7 gpm/sf, and the granular carbon used should be an 8 x 30 mesh.

Carbon adsorption is the only method currently economical for removing refractory organics from treated wastewaters; reverse osmosis, ion exchange, distillation, or freezing are not yet competitive.

As a rule, activated carbon cannot be expected to remove reducing sugars from food processing wastewaters. However, some organic acids can be removed.

If the influent contains high concentrations of BOD and COD, the column can become anaerobic and produce hydrogen sulfide. This is generally not a problem with filtered secondary effluent. At any rate, the problem can be solved by

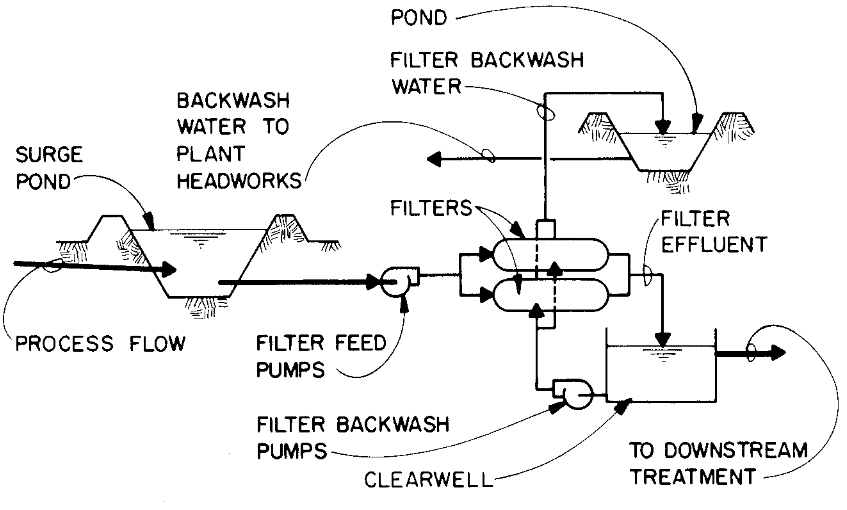
TABLE 4.13
COST SUMMARY FILTRATION

CRITERIA

• FLOW:	1 MGD AVERAGE 2 MGD PEAK
• BOD:	1000 mg/l
• TSS:	1000 mg/l
• pH:	4.5
• SEASON:	90 DAYS
• AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- TWO PRESSURE FILTERS WITH 2.5 GPM/FT^2 APPLICATION RATE
- 18 GPM/FT^2 BACKWASH RATE
- LINED EARTHEN SURGE POND
- CONCRETE CLEARWELL

COSTS

CAPITAL
$271,000

OPERATION AND MAINTENANCE	
LABOR	$ 2000/yr
POLYMER	1700/ yr
MISCELLANEOUS	300/ yr
TOTAL	$ 4,000/yr

AMORTIZED CAPITAL PLUS O & M	$51,960/yr
UNIT COST	57.7¢/1000gal

frequent backwashing, chlorination, or the addition of sodium nitrate.

4.244 ION EXCHANGE

There are many applications of ion exchange, from the selective removal of specific substances such as ammonia, phosphates, or nitrates, to the complete demineralization of water.

Ion exchange to remove calcium and magnesium is currently practiced by many processors for boiler water treatment. Regenerant for these softeners is sodium chloride.

The simplified equations below show the action of a typical cationic ion exchange resin during both use and regeneration. "R" indicates the resin.

Use: $RNa_2 + Ca^{++} \rightarrow RCa + 2Na^+$

Regeneration: $RCa + 2NaCl \rightarrow RNa_2 + CaCl_2$

Demineralization of wastewater requires both cationic and anionic resins to remove cations (like sodium) and anions (like phosphates), respectively. These can be mixed in a single bed, but more often they are set up in a series of separate beds. Since 1965 pilot tests on ion exchange have been run in Pomona, California, where carbon column effluent is used as the feed water. The system contains four resin beds in series: two cationic and two anionic. The cationic resins are regenerated with sulfuric acid and the anionic with ammonia. Historically, removals have been as follows:

COD	63.0 percent
Total Dissolved Solids	86.7 percent

Thirteen percent of the volume treated becomes a waste brine.

Pilot work by Rohm and Haas, Inc., using their modified Desal ion exchange process on disinfected secondary effluent, gave the following removals:

COD	83.3 percent
TDS	Approximately 90 percent

No full-scale, long-term installations of ion exchange for dissolved solids reduction have been operated on wastewater. Little work has been done on a pilot scale to test dissolved solids removal in food processing wastewater.

Three of the largest problems in the use of ion exchange are (1) achieving efficient regeneration of the resin, (2) the disposal or recovery of the waste regenerant solution, and (3) the length of the resin life.

4.245 REVERSE OSMOSIS

The natural process of osmosis has been known since the middle of the eighteenth century, but it was not until the 1950's that experiments were conducted in reverse osmosis. If fresh and saline water are separated by a semipermeable membrane, the natural tendency is for the fresh water to migrate through the membrane into the saline water until the concentrations of the salts on both sides of the membrane are equal. The driving force to accomplish this appears as a pressure differential called osmotic pressure. In reverse osmosis this osmotic pressure is overcome by pressurization to reverse the process, thereby leaving the salts behind and producing fresh water from saline water.

The semipermeable membrane is now commercially made of a cellulose acetate. While reverse osmosis has found application in the reclamation of seawater and brackish water, use on wastewaters has fouled the membrane. In theory reverse osmosis has the capacity to remove more than 90 percent of inorganic ions and most organic matter.

The most extensive experience in reverse osmosis has been gained from pilot plants in Pomona, California. There, the units achieved the following removals from domestic activated sludge effluent:

COD	88.5 percent
TDS	92.1 percent

Twenty-five percent of the volume treated went to waste as brine, but this fraction can be reduced to 15 percent. The flux, or flow rate, through the membrane was about 10 gpd/sf. Pressure used was 750 psi.

Some low-molecular weight organic compounds like amines, alcohols, and acids are not removed by reverse osmosis. Reverse osmosis has the greatest potential for technological improvement of any process for removing dissolved solids. Currently, though, reverse osmosis is costly. Work is continuing to increase the flux, to increase the product-to-waste ratio, and to develop methods of disposal of the highly concentrated brine.

4.246 CHLORINATION

Disinfection by chlorination is often practiced in domestic water and wastewater treatment. Disinfection is required because disease-carrying organisms, or pathogens, are present in the water or wastewater. Chlorination is also used in the fruit and vegetable processing industries for odor and slime-growth control in flumes and process units (see Section 2.2).

As long as sanitary or domestic waste is kept separate from processing wastewater, there should be no need for final disinfection for pathogen removal. However, some food processors are disinfecting the effluent from their secondary treatment plants.

For 1983 EPA has set guidelines for the effluent fecal coliform count at or less than 400 MPN (Most Probable Number) per 100 ml[1,2]. This guideline will probably not require chlori-

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[1] Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines for the Apple, Citrus, and Potato Processing Categories," March 1973.

[2] Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines . . . for the Fruits and Vegetables Point Source Category," October 1975.

TABLE 4.14

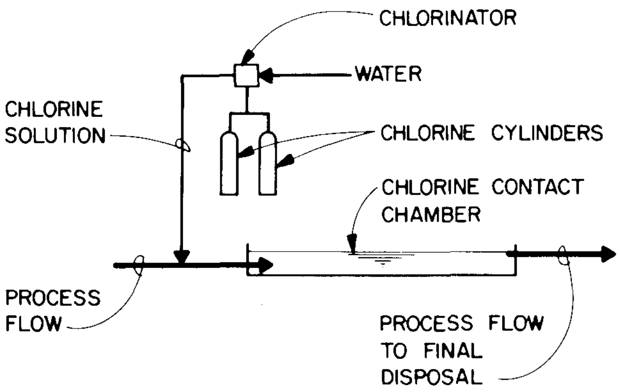
COST SUMMARY CHLORINATION SYSTEM

CRITERIA

• FLOW:	I MGD AVERAGE 2 MGD PEAK
• BOD:	1000 mg/l
• TSS:	1000 mg/l
• pH:	4.5
• SEASON:	90 DAYS
• AMORTIZATION:	10 YEARS AT 12%

- ENGINEERING, LEGAL AND CONTINGENCY COSTS INCLUDED AT 25% OF CONSTRUCTION COST
- OCTOBER, 1975 DOLLARS

SCHEMATIC



ASSUMPTIONS

- ∘ CONCRETE CHLORINE CONTACT CHAMBER WITH I HOUR DETENTION TIME AT AVERAGE FLOW
- ∘ CHLORINE DOSAGE AT 10 mg/l
- ∘ CHLORINE COST AT 27.5 CENTS/POUND
- ∘ SMALL CHLORINATION BUILDING INCLUDED

COSTS

CAPITAL	OPERATION AND MAINTENANCE	
$38,000	LABOR	$ 600/yr
	CHLORINE	2200/yr
	TOTAL	$2,800/yr

AMORTIZED CAPITAL PLUS O&M	$9,530/yr
UNIT COST	10.6¢/1000 gal

nation if sanitary waste is not included in the processing wastewater. Fecal coliforms do not usually multiply outside the intestines of mammals. Exceptions have been noted in high carbohydrate wastewaters, such as sugar beets.

If the effluent fecal coliform count for a plant exceeds the EPA limitation or if a local requirement is based on total coliforms, then disinfection will be required. A cost estimate for chlorination of 1.0 mgd of secondary effluent is given in Table 4.14. The critical assumptions in the estimate are given in the table.

Chlorine also oxidizes BOD and some organic compounds. Thus, the additional chlorine demand of these compounds must be satisfied before adequate disinfection can occur. This has proved to be a major problem in stabilization pond effluent where the algae exerts a high chlorine demand.

4.25 Complete Treatment Systems

It is our intent here to briefly summarize application of the individual unit treatment processes discussed previously – that is, application of the individual processes to comprise a complete treatment system. Of necessity, the approach here must be simplistic, taking into account only a few of the many variables considered in complete system formulation. Selection and sizing of system components should be undertaken with professional guidance to formulate a design meeting the specific wastewater as well as other local site and environmental conditions at hand.

Formulation of a complete system must be preceded by preliminary considerations including:

- Wastewater quantity and character to be treated (see Sections 1 and 3).
- Treatment requirements and discharge limitations imposed at all governmental levels (see Section 6.11).
- Climatic conditions.
- Available plant site size, configuration, and character.
- Adjacent land use.
- Local construction and operating cost conditions.

With knowledge of the foregoing and food processing wastewater treatment practices, it is possible to select and design a cost-effective and successful wastewater treatment plant.

The need for knowledge of wastewater quantity and character is obvious, as is the need for a knowledge of treatment requirements and effluent limitations. From this information can be formulated design criteria to include:

- Quantity and character of all pollutants (BOD, suspended solids, etc.) to be discharged to treatment.
- Mass quantity and percent removal of each pollutant required.

Climatic conditions will influence system selection, with colder climates generally mandating more extensive treatment or different treatment to remove a given quantity of pollutant. Extremely cold conditions do not favor secondary treatment systems with large surface areas exposed to heat loss. A closed high-purity-oxygen activated sludge system may, for instance, be preferred to an open complete-mix activated sludge system.

Available plant site size and other characteristics have considerable impact on system selection. Site size is of particular

TREATMENT CATAGORY	IN-PLANT	PRE-TREATMENT	PRIMARY TREATMENT	SECONDARY TREATMENT	TERTIARY TREATMENT
Unit Processes	*Conservation & Reuse of water* *Process revisions* *Process control etc.(See section2)*	*Screening etc. (See section 4.1)*	*Sedimentation* *Flotation*	*Trickling filters* *Activated sludge* *Stabilization ponds* *Anaerobic filters* *Anaerobic ponds* *Aerated lagoons*	*Chemical treatment* *Carbon adsorption* *Filtration* *Ion exchange* *Reverse osmosis*
				Land Treatment (See section 4.3)	
Unit Sequences					

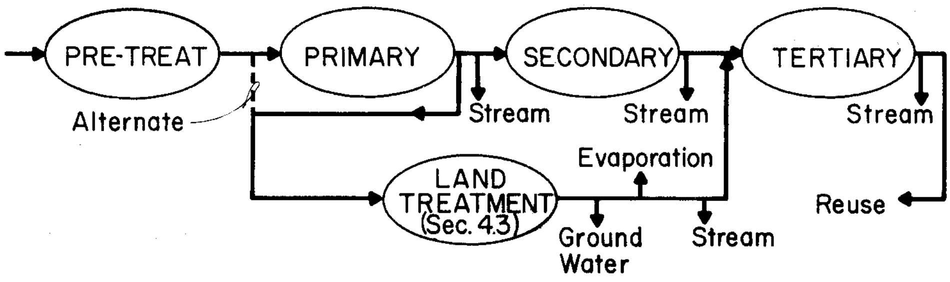


Figure 4.23. Unit process sequence.

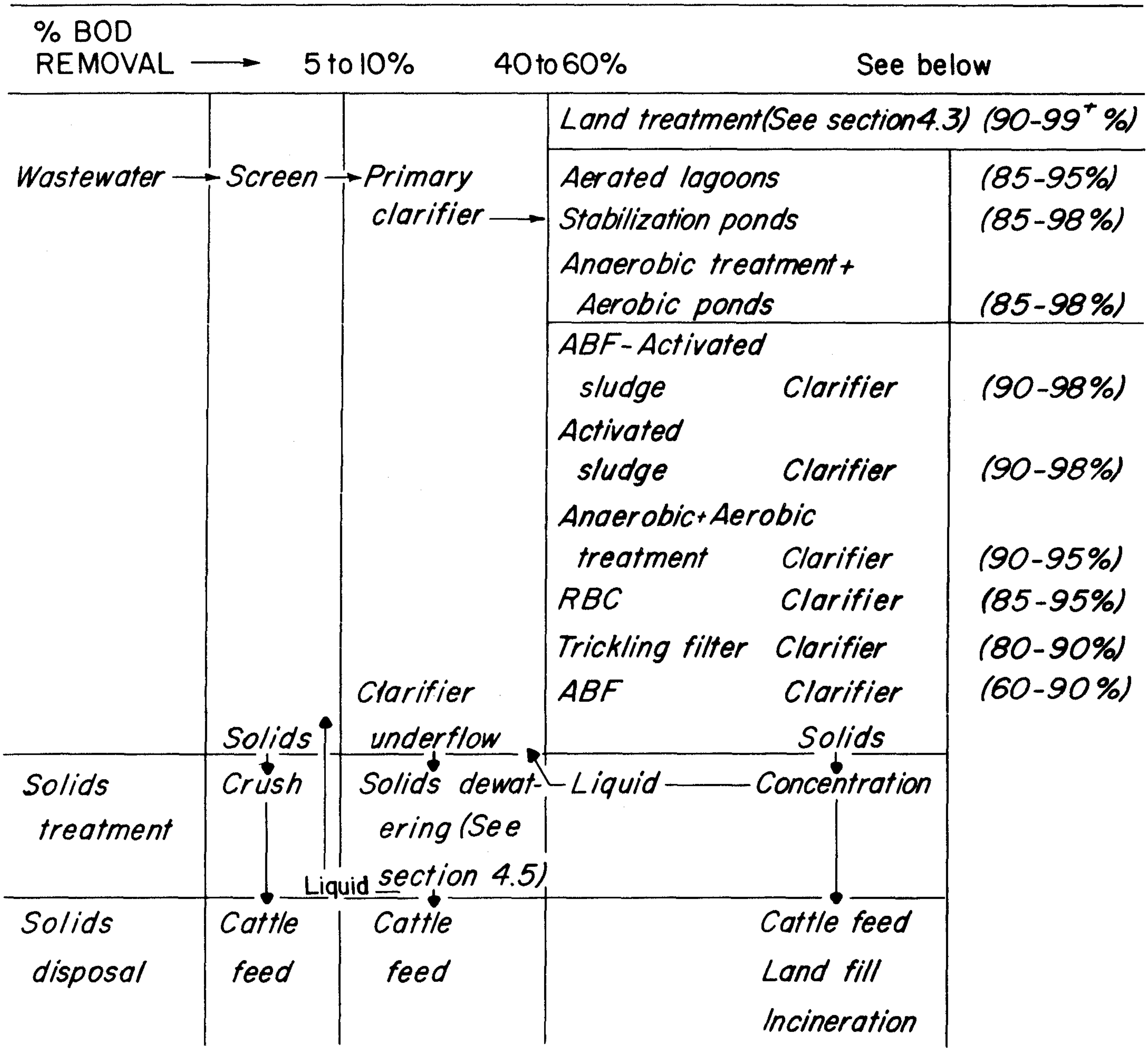


Figure 4.24. Food (potato) processing wastewater treatment.

concern here. Many systems discussed, such as the pond and aerated lagoon systems, take considerable land. These land intensive systems are prone to great cost variation with variation in topographic and subsurface conditions.

Adjacent land use is increasingly important as noise, odor, and visual constraints find their way into ordinances and court action. A poorly covered anaerobic pond located "out in the country on the other side of the feed lot" may be perfectly acceptable, but definitely not when located "next to the plant on the upwind edge of town."

Local construction and operating costs can greatly affect system component selection. This is particularly true as it relates to energy costs (even energy availability). Relatively low power costs in the Pacific Northwest may favor an activated sludge plant; however, the high electrical costs in the Northeast may make this same plant the most costly option available.

Figures 4.23 and 4.24 are presented to summarize the complete treatment system components presented previously and to introduce one additional approach to treatment: land treatment described in Section 4.3. Figure 4.23 presents the unit process sequence while Figure 4.24 presents principal interrelationships between unit processes through secondary treatment. Anticipated BOD removals in treatment of a potato processing wastewater are also presented on Figure 4.24. BOD removals indicated are "ball-park" only. Actual removals experienced will depend upon the design employed, climatic conditions imposed, and operational skill and attention provided.

4.3

LAND TREATMENT

Land treatment is the application of wastewater to land by conventional irrigation procedures. Figures 4.23 and 4.24 in the preceding discussion of complete treatment systems array land treatment with the various secondary and tertiary "treatment plant" systems of more conventional character.

Treatment in a land treatment system is provided by natural processes (chemical, physical and biological) as the wastewater moves through the "filter" provided by the cover crop and soil mantle. Part of the water is lost to the atmosphere by evapotranspiration; part to surface water by overland flow; and the remainder percolates to the ground water system. The method of application, the site, and the loading rate determine the percentage of flow to each destination.

Land treatment is deceptively simple. Although there are many successful systems, there are also many which have and will fail as a result of misapplications and increasing restrictions on ground water quality, surface runoff, air quality, and other environmental factors.

System failures do not usually occur in the first few years. Failure is more likely to occur after 5 years or more. The common symptoms and causes of failure are:

Symptom	Cause
Runoff resulting from decreased soil permeability	Solids build-up on or in soil. Physical and chemical changes in soil.
Runoff resulting from organic overload	Slime layer forms on surface of ground. Root zone becomes anaerobic.
Increase in ground water nitrate	Accumulation of nitrogen in soil and percolation to ground water.
Decreases in cover crop quality	Nutrient imbalance.
Mounding of water under the site resulting in cover crop loss	Horizontal movement of water in soil not adequate to keep ground water below root zone.
Salt build-up in soil resulting in crop loss	Salts from wastewater concentrated in soil as result of evaporation and transpiration.

These problems can be avoided or corrected with good engineering, care in construction, and system management.

4.31 Process Variations

Land treatment systems vary in several ways. For discussion we will divide these into four basic processes. The four variations (described in Table 4.15) are: overland flow, irrigation, high-rate irrigation, and infiltration-percolation (Figure 4.25). Most food processors use some kind of high-rate irrigation by spray nozzles.

The objectives and characteristics of each of the four processes are distinctly different. The most suitable process depends on the characteristics of the site, the type of wastewater to be applied, and environmental regulations. Overland flow is especially suited to the treatment of wastewater high in BOD and suspended solids, such as from tomato processing. Removal efficiencies greater than 90 percent have been reported for processing plants using overland flow. The infiltration-percolation process is least suited to treatment and disposal of high BOD and suspended solids wastes because most of the wastewater, with its pollutants, enter the ground untreated.

TABLE 4.15

LAND TREATMENT PROCESSES

Process	Objective	Suitable Soils	Typical Annual Application	Dispersal of Applied Water	Impact on Quality of Applied Waste
Overland Flow	Maximize waste treatment. Crop is incidental. Allow runoff.	Slow permeability and/or high-water table.	60 – 300"	Most to surface runoff. Some to evapotranspiration and ground water	BOD and SS greatly reduced. Nutrients reduced by fixation and crop growth. TDS increased in runoff.
Irrigation	Maximize agricultural production.	Suitable for irrigated agriculture	12 – 60"	Most to evapotranspiration. Some to ground water; little or no runoff.	BOD and SS removed. Most nutrients consumed in crop or fixed. TDS greatly increased in percolated water.
High-Rate irrigation	Maximize waste treatment by evapotranspiration and percolation without runoff; crop production a side benefit.	More permeable soils suitable for irrigated agriculture; may use marginal soils if coarse texture.	24 – 120"	Evapotranspiration and ground water; little or no runoff.	BOD and SS mostly removed. Nutrients reduced. TDS substantially increased in percolated water.
Infiltration-Percolation	Recharge ground water or filter water; crop may be grown with little or no benefit.	Highly permeable sands and gravels.	240 – 6000"	To ground water, some evapotranspiration; no runoff.	BOD and SS reduced. Little change in TDS of percolated water.

Some nutrients are used by crops in overland flow, but most will be carried away in runoff water. Most of the nutrients are carried into the ground water or subsurface drainage system in the infiltration-percolation process. Few, if any, plants are grown on the site for nutrient uptake.

The irrigation process is most effective for removing the nutrients in wastewater. The application rate is limited so the nutrient loading does not exceed the crop nutrient requirement. The nutrients are removed from the site by crop harvest.

4.32 Application Methods

Three methods are commonly used for application of wastewater: (1) sprinkler irrigation, (2) surface irrigation, and (3) drip (or trickle) irrigation. In sprinkler irrigation water is sprinkled onto the land to simulate rainfall (Figure 4.26). Sprinkler and surface irrigation are most commonly used for wastewater application. Wastewater is distributed in furrows or small channels, or by flooding in surface irrigation. With drop irrigation water is applied through small holes (emitters) spaced along the supply line. Drip irrigation is impractical for use with wastewater because suspended material can clog the holes.

The selection of an application method depends on soil characteristics, crop, operation, maintenance, topography, costs, water supply, weather, and need for control of runoff. Each method has distinct advantages.

Distribution of wastewater by sprinkler irrigation is controlled by the selection and design of the equipment used. Surface irrigation depends on soil permeability and soil uniformity for an even distribution of wastewater. If soil conditions are suitable, surface irrigation normally offers economic advantages in power and hardware requirements. Both methods have been used in freezing conditions.

4.33 Pretreatment Requirements

Some pretreatment of wastewater before land application is normally necessary. The wastewater is usually screened even when the suspended solids concentration is low. Screens (10 to 20 mesh) are necessary to prevent clogging of sprinkler nozzles. Silt and other suspended particles that may hinder operation of the distribution and application system should be removed. The pH of the wastewater must be controlled for application on land. Wastewater pH outside the range of 6.4 to 8.4 may render some nutrients inaccessible to plants.

Oil and grease may have to be removed to avoid soil sealing. Removal of sodium or other specific ions may also be necessary to avoid loss of infiltration capacity or poisoning of plants.

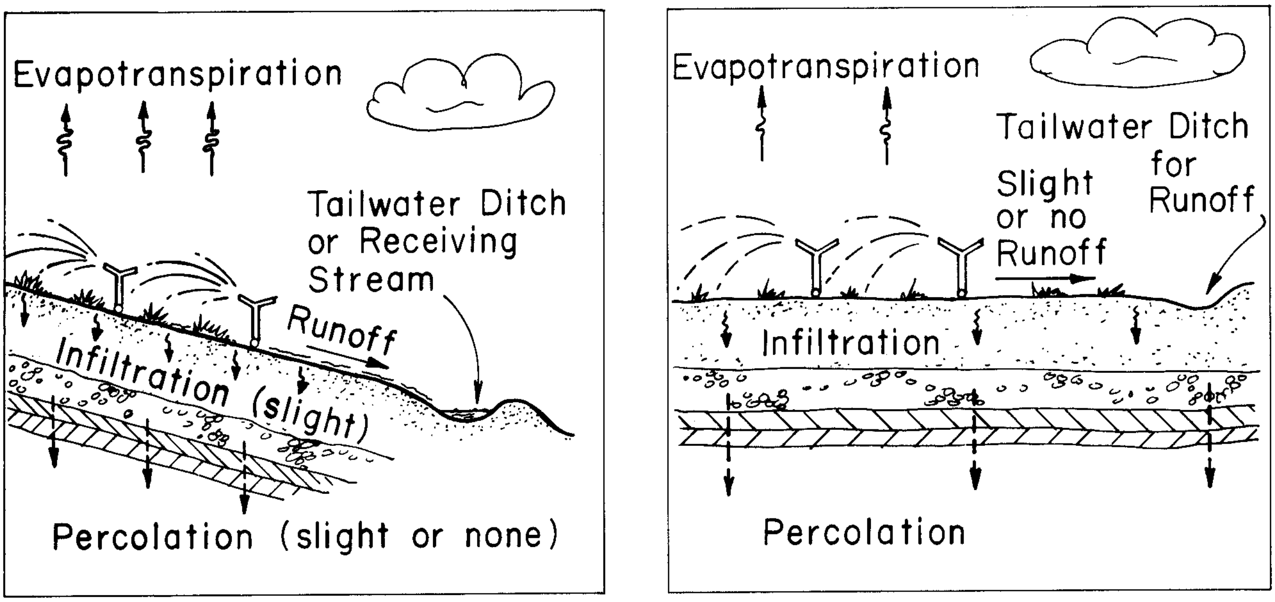
4.34 System Selection

The various processes and application methods are not necessarily interchangeable. The process selected will depend on the specific waste, the specific site, and discharge limits. Some wastewater characteristics influencing the selection are solids, BOD, nutrients, salts, and pH.

4.341 LOCATION

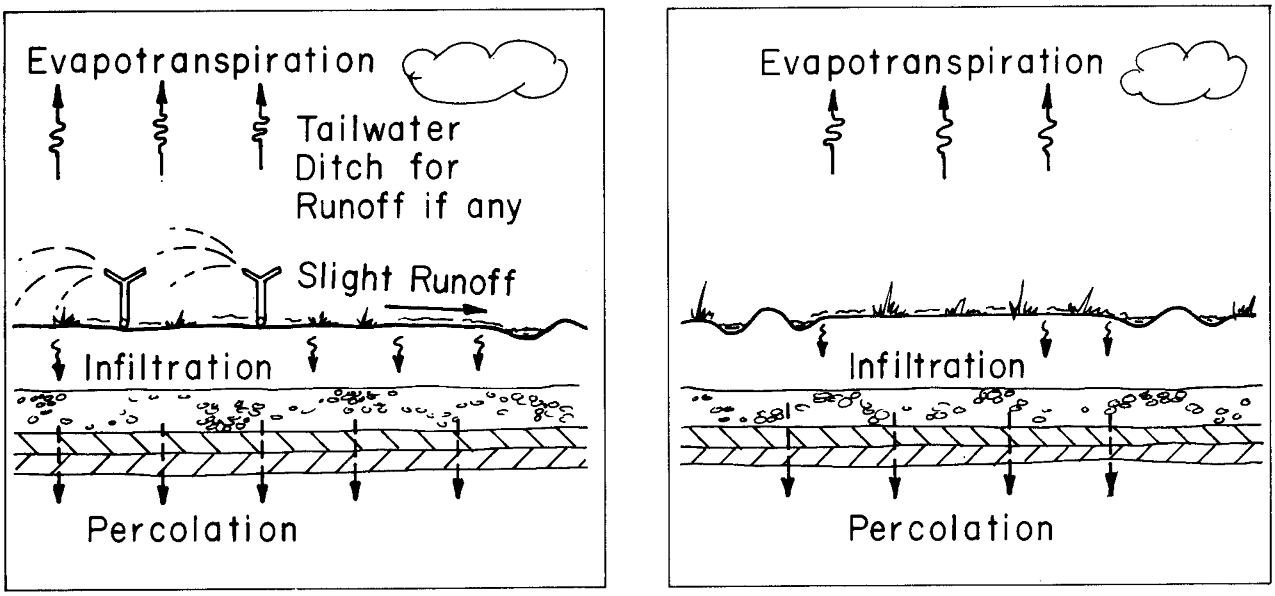
Site characteristics that will influence selection include:

- Soil and topography must be suitable for the land treatment process (overland flow, irrigation, high-rate irrigation, and infiltration-percolation).
- Areas with continual winds (greater than 10 mph) cannot be used without generous allowances for sprinkler droplet drift.
- Slopes must not exceed 15 percent.
- The site must not have shallow ground water depths (less than 4 to 5 feet), even during periods of wastewater application.



OVERLAND FLOW

IRRIGATION



HIGH-RATE IRRIGATION

INFILTRATION-PERCOLATION

Figure 4.25. Land treatment processes.

- The site should be a short distance from the processing plant, and it must be easily accessible.
- The site should allow for buffer zones, sight screens, roads, etc.
- The site preparation requirements must not be prohibitive.
- The site must be properly zoned.
- The site should be situated to allow expansion.

Discharge limits that will influence selection include:

- Permissible nitrate in ground water.
- Limits on runoff.
- Limits on constituents in applied wastewater or harvested crop.

4.342 LOADINGS

The amount of liquid that can be applied depends on the infiltration and percolation capacity of the soil. Discharge quality limits placed on deep percolation to ground water or return flow to surface streams may require a limited loading rate or extensive pretreatment. A soil-crop system has a finite capacity for removal of various pollutants. If this capacity is exceeded, the system will eventually fail. Odor will

Figure 4.26. Spray irrigation system.

develop, and pollution of ground water or a nearby stream can result.

The various constraints on loading may be classified as hydraulic, treatment, and chemical:

Hydraulic Constraints

- Infiltration capacity of the soil
- Permeability of the root zone
- Permeability of the underlying soil

Treatment Constraints

- Capacity of the soil to remove and oxidize BOD
- Capacity of the soil to filter and assimilate suspended solids

Chemical Constraints

- Capacity of the soil to remove major plant nutrients (nitrogen, phosphorus and potassium)
- Sensitivity of the soil to other wastewater characteristics such as salt content, sodium-adsorption ratio, and pH

4.3421 Hydraulic Constraints

The infiltration capacity of a soil is the rate at which water can be applied without runoff. Previous erosion or lack of a dense vegetative cover will reduce infiltration capacity and require a reduction in application rates. The infiltration capacity of the soil will influence the choices of irrigation methods. Infiltration rate limits the instantaneous (daily or hourly) rate of application but rarely will it limit the total seasonal application.

The permeability of the soil will determine the total effluent and precipitation that can be applied. In a year with high rainfall the amount of effluent which can be applied must be reduced. Permeability determines the allowable percolation rate.

Three to five feet of aerated soil is required in the root zone to provide sufficient treatment of the applied effluent. If the permeability of the site is not adequate for the amount of waste applied, the ground water will raise into the root zone and drown the cover crop, causing treatment failure.

If no runoff is allowed, the maximum hydraulic loading is the sum of the soil moisture depletion by evapotranspiration, plus the quantity of waste that can be transmitted through the root zone. Maximum hydraulic loadings, less evapotranspiration under ideal conditions for different soils, are given in Table 4.16.

To avoid runoff, or ponding on the surface, the instantaneous sprinkler-application rate should not exceed the infiltration rate (measured in inches per hour). The following are typical infiltration rates for these soil types:

Fine sand	1.0+ inches/hour
Sandy loam	0.5 – 1.0
Silt loam	0.3 – 0.7
Clay loam	0.2 – 0.4
Clay	0.1 – 0.2

TABLE 4.16

ESTIMATED MAXIMUM HYDRAULIC LOADING OF WASTEWATER FOR VARIOUS SOIL TEXTURES (IDEAL CONDITIONS)

	Movement Through the Soil Root Zone*	
	Infiltration Rate Inches/Day**	Percolation Rate Inches/Year***
Fine Sandy	15.0	300
Sandy Loam	7.5	180
Silt Loam	3.5	90
Clay Loam	1.5	40
Clay	0.5	10

*Does not include evapotranspiration.

**Rate not to be exceeded on any one day. Reduce if site is sloped.

***Rate not to be exceeded in a growing season (or year).

4.3422 Treatment Constraints

Biochemical oxygen demand (BOD) is associated with both suspended solids and dissolved organic material. The BOD associated with suspended solids will remain close to the surface where the soil organisms have access to atmospheric oxygen to break the material down. The BOD in the dissolved organic material will percolate through the unsaturated zone of the soil and, under aerobic conditions, be removed during percolation. If the loading is too great, the soil will become anaerobic, and the crop and treatment process will fail. Table 4.17 lists typical BOD loading constraints for various soil conditions.

Experience indicates that higher loadings are possible if the site is only irrigated for a few weeks each year and is well maintained.

Clogging of soil is most often due to incomplete biological breakdown of organics in an anaerobic environment. Aerobic conditions can be maintained by intermittent application of the allowable amount of waste. A day of application followed by several days of rest is typical.

If the soil becomes sealed with inert suspended solids, such as silt, it can usually be opened by harrowing or disking. The amount of silt which can be accepted without a loss of permeability can be estimated from an analysis of the soil and the inert solids.

Suspended solids of up to 200 lbs/acre/day have been applied. However, a loading limit of about 70 pounds per acre per day is more typical.

4.3423 Chemical Constraints

Typically, the nitrogen found in fruit and vegetable wastewaters is mostly in the organic form. All of the nitrogen is not immediately available for plant use. The "mineralization rate" of organic nitrogen to nitrate is such that, at least for domestic sewage sludges, 20 to 30 percent of it becomes available for plant use in the first year, 5 percent in the second, 2 percent in the third, and so on. Recent information indicates that the mineralization rate for food processing wastewater is 50 to 100 percent higher than that for domestic sludges, with up to 40 percent mineralization in the first year.

Nitrate is the only nitrogen form used by crops. Removing the grown crops is a major method of removing nitrate from the soil.

For land treatment systems in which no runoff or percolation to the ground water is allowed, the rate of total nitrogen applied should be controlled to match the nitrogen removed in the crop (100 to 300 pounds per acre per year depending on the extent of irrigation, climate, crop, soil, temperature, etc.) plus the amount lost through nitrification-denitrification.

If nitrogen application is not controlled, the excess nitrogen (beyond that removed by the crop plus that nitrified-denitrified) will enter the ground water or receiving stream as nitrate. The nitrification-denitrification mechanism will only work if an anaerobic soil layer is present below the aerobic surface layers– a condition which is not controllable.

Caustic peeling processes used for commodities such as potatoes and peaches may result in high sodium wastes. These can reduce permeability in some clay bearing soils. The potential effect of sodium on the soil is measured by the sodium-adsorption ratio, SAR, of the waste.

$$SAR = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)}$$

where Na, Ca, and Mg are measured in equivalents per liter.

Generally, the SAR must not exceed 6.0 to 9.0, depending on the soil. Gypsum ($CaSO_4$) can sometimes be applied to the soil to increase the amount of sodium that can be applied. If the SAR of the wastewater is high, added soils analysis will be necessary to determine if the wastewater can be applied directly, or if the sodium should be eliminated from the wastewater.

Some wastewater may contain certain constituents that retard plant growth or present potential health hazards. Table 4.18 lists recommended concentration limits of these constituents for continuous application on non-sandy, non-acidic soils.

4.35 Operation and Management

The major tasks involved in operating a land treatment system include: (1) maintaining the proper application rate and frequency, (2) managing the soil and cover crop, and (3) monitoring the performance of the system. Scheduling wastewater applications will depend on the weather. During wet

TABLE 4.17

BOD LOADINGS IN LAND TREATMENT

	lbs/acre/hr	Average During Season lbs/acre/day
Irrigation & High-Rate Irrigation		
Fallow soil with no fresh organics	1 – 2	36
Fallow soil following addition of organic residues	2 – 4	72
Soil with growing plants	3 – 6	108
Estimated recommended maximum BOD load to be added on well aerated soil		100
Overland Flow		40 – 100
Infiltration/Percolation		600

TABLE 4.18
RECOMMENDED MAXIMUM LIMITS OF INORGANIC CONSTITUENTS IN LAND APPLIED WASTEWATER

Inorganic Constituents	Recommended Limit for Irrigation on All Soils
Aluminum, mg/l	5.0
Arsenic, mg/l	0.10
Beryllium, mg/l	0.10
Boron, mg/l	0.50
Cadmium, mg/l	0.01
Chloride, mg/l	70.0
Chromium, mg/l	0.10
Cobalt, mg/l	0.05
Copper, mg/l	0.20
Fluoride, mg/l	1.0
Iron, mg/l	5.0
Lead, mg/l	5.0
Lithium, mg/l	2.5
Manganese, mg/l	0.20
Molybdenum, mg/l	0.01
Nickel, mg/l	0.20
Selenium, mg/l	0.02
Vanadium, mg/l	0.10
Zinc, mg/l	2.0
Sodium-Adsorption Ratio	6.0 – 9.0
pH	6.4 – 8.4

months the amount that can be applied will depend on the daily precipitation. Applications will also have to be coordinated with harvest. For the most efficient operation of the system during the wet months, application should be scheduled on a daily basis to incorporate the daily measurement of precipitation and not exceed the application criteria. Thus, a storage pond is often required to hold the wastewater during times it cannot be disposed. This pond must be adequately aerated to prevent odors.

Experience with potato wastewaters has shown that both spray and surface irrigation facilities can be operated during winter months when the field ices. Ice accumulates during the winter and melts in the spring. The thaw is usually gradual enough that BOD loading rates are not greatly exceeded and odors do not occur. If the thaw is too fast, groundwater pollution and odor can result.

Proper soil management is required to maintain the infiltration rate and prevent erosion. To accomplish this a healthy cover crop should be established and general soil conservation practiced.

Grasses and other crops keep the infiltration rate high by preventing droplets from sprinkler irrigation from puddling and sealing the surface. A good cover crop is also necessary to

TABLE 4.19
COMPARISON OF CAPITAL AND OPERATING COSTS FOR 1-MGD SYSTEMS[1]

	Spray Irrigation	Overland Flow	Infiltration-Percolation
Liquid loading rate, in/wk	2.5	4.0	60.0
Land use, acres	103	64	–
Land required, acres[2]	124	77	5
Capital costs			
Earthwork	12,700	79,100	12,400
Pumping station	61,800	61,800	–
Transmission	163,200	163,200	163,200
Distribution	178,000	79,000	6,200
Collection	–	7,400	37,100
Total capital cost (excluding land)	415,700	390,600	218,900
	$ 3,352/ac.	$ 5,072/ac.	$ 43,780/ac.
Amortized cost[3]	73,600	69,100	38,700
Annual operating cost			
Labor	12,400	12,400	9,300
Maintenance	24,000	14,800	4,300
Power	7,200	7,200	2,200
Total operating cost	43,600	34,400	15,800
Total equivalent annual cost	117,200	103,500	54,500
Total cost, ¢/1,000 gal.[4]	130.2	115.0	60.6

1. Updated estimate for October 1975 dollars, ENR index 2300, from 1973 ENR of 1960
2. 20% additional land purchased for buffer zones and additional capacity 12%, 10 year life
3. 12%, 10 year life
4. 90-day season assumed, hence annual flow is 90 million gallons

UPDATE FROM: *Wastewater Treatment and Re-Use by Land Application*
Prepared for Office of Research and Development, U.S. Environmental Protection Agency, August 1973.

remove nutrients from the soil treatment system. The crops must be periodically harvested and removed from the site. Monitoring the wastewater characteristics, the soil, the crop, ground water, and runoff are very important for successful operation of a land treatment system. Monitoring will also give advanced warning of developing problms. Failure in any part of the system, wastewater quality, soil infiltration, crop growth, or groundwater drainage can eventually cause failure of the whole treatment system.

4.36 Costs of Alternative Application Methods

Costs for different land treatment systems are compared in Table 4.19. This table is an updating of "Table 28" in an EPA publication on land treatment. In this earlier EPA report, several assumptions were made which are not consistent with those made for the cost summaries in this report. Thus, the costs in Table 4.19 are only useful in illustrating the comparative costs of the three land treatment systems. They should not be compared with the other cost estimates in this report.

4.4

FINAL DISCHARGE

Removal of pollutants in wastewater treatment is never 100 percent effective, even when the most advanced and complete facilities are provided. The task of further treatment always falls to the recipient of the treated discharge – this can be either a water body such as ground water, a stream or a lake, or it may be another and more complete wastewater treatment plant. If the recipient is another wastewater treatment plant, it will almost always be a public facility intended for joint treatment – a situation discussed subsequently in this section. First, however, some consideration needs to be given to discharges to natural waters and to the land.

The natural environment, including receiving waters, can assimilate treated wastewater while maintaining a quality sufficient to accommodate other demands on it. This has been an underlying premise throughout the history of wastewater treatment and holds true even today. The variables in the equation of wastewater discharge-receiving water assimilation are: (1) quantity and character of the receiving water, (2) the competing beneficial uses (drinking water supply, water contact sports, fish life, etc.) of the receiving water, and (3) the associated water quality parameters determined necessary to ensure protection for the competing beneficial uses. Because the foregoing variables are never the same from one situation to another, the degree of treatment required prior to discharge and the means of discharge itself varies considerably.

Discharges should be rapidly and effectively mixed with the receiving water to minimize adverse impacts and facilitate the natural purification processes. This frequently calls for use of a diffuser in the receiving water. Once mixed with the receiving water, the pollutants are removed and/or stabilized in much the same fashion as these same constituents are removed in secondary and tertiary treatment processes. BOD removal in natural waters was briefly alluded to in Section 4.232.

Special considerations must be given to heated effluent, or thermal, discharges. Rapid mixing of the discharge with the receiving water is necessary to minimize the temperature gain. Temperature changes in the receiving stream should be kept to only a few degrees, generally less than 5°F, to avoid thermal shock to aquatic life crossing the thermal interface. The maximum temperature permitted in the receiving water will vary with the natural ambient water temperature and the fish and other aquatic life present. Trout and related fish species find survival difficult above 70°F and don't generally spawn at temperatures much above 60°F, while bass and related warm water species may tolerate temperatures into the 90's. Where receiving water temperatures in excess of allowed would result from thermal discharges, prior cooling in cooling towers, cooling ponds, or cascades is necessary.

Each industry discharging to a receiving water must have a permit under the National Pollutant Discharge Elimination System (NPDES permit). Industries discharging to land or to municipal sewers may also be required by the state or city to have a discharge permit. Although the EPA guidelines focus on process wastes, permits set restrictions on all discharges – cooling water, sanitary waste, and storm drainage.

4.41 Streams and Rivers

Streams and rivers receive most effluent discharges simply because of their abundance. Most food processing plants not located within a municipality are located adjacent to a stream. These streams receive pollutant loadings from both natural and man-made sources. Fortunately, streams and rivers are more capable of cleansing themselves than are other natural waters. Principal among the natural processes purifying a stream are: the action of microorganisms and higher life forms in consuming organic pollutants, sedimentation on the stream bed, and flushing which occurs during high flow conditions.

Oxygen necessary for life and natural purification processes in a stream is obtained through surface reaeration from the atmosphere and by photosynthesis of algae and aquatic plants. Atmospheric reaeration rates are directly proportional to the dissolved oxygen deficiency (saturation concentration less stream concentration). Reaeration rates increase with stream flow, velocity, and turbulence (caused by bottom irregularities, rapids, falls, etc.) and decrease with stream depth. Photosynthesis increases with sunlight and decreases with turbidity.

Minimum acceptable dissolved oxygen levels in our streams and rivers vary with the tolerance of the resident fish population for low oxygen concentration. Consideration of minimum oxygen levels for fish life generally places the minimum diurnal dissolved oxygen standard at or above 2 mg/l, with a 5 mg/l diurnal minimum being common. When any portion of the oxygen supply to a stream results from photosynthesis, there will be a diurnal variation, with the oxygen concentration peaking in the late evening and being at its lowest level around dawn.

Discharge standards are generally most stringent during the summer months. Several year-round industries have been prohibited from discharging to watercourses during the summer or during fish migration periods. To accommodate these periods, large storage ponds are constructed or disposal is made to land.

4.42 Lakes

Only a relatively small percentage of food processing plants discharge effluent to lakes and, as such, lakes are of less interest than rivers and streams. Lakes, particularly large lakes, have considerable capacity to assimilate pollution. Unfortunately, they can be more easily damaged by loading excesses than can streams and rivers. Once the ecological balance of a lake is upset, it is slow to recover.

Lakes possess similar oxygenation abilities as do streams. Wind-generated wave action provides for good reaeration. This same wave action and associated currents mix wastewater pollutants with the lake contents. Here the similarity with streams ends, however. Solids discharged to and formed in lakes settle to the bottom. Lakes have little ability to flush themselves. The only discharge of residual pollutants (those not removable by natural processes in the lake) is via the outlet or seepage to ground water. This outflow is usually small when compared to the lake volume. As a result, lakes tend to become pollutant sinks, concentrating much of the non-biodegradable pollutants and nutrient load received. The lake becomes eutrophic when nutrients become sufficiently concentrated – that is, algae growths become excessive, the lake becomes turbid, much of the fish and other aquatic life decreases, and odors may be emitted.

From a purely ecological point of view, a stream discharge is preferable to a lake discharge except, obviously, where the receiving stream discharges to a lake. This preference is based on the premise that an ecological imbalance created in a river is more rapidly and completely corrected than is the same imbalance in a lake.

4.43 Ocean

Ocean disposal is generally of less interest than lake disposal. This is not because of any inadequacy of the ocean to assimilate wastewaters – the ocean is excellent in this regard. Rather, it is because: (1) few processors other than seafood processors are located sufficiently close to the ocean to use it as a receiving water, and (2) in areas where tidal flushing is inadequate, acceptable ocean outfalls, which are of complex design and usually quite expensive, are generally required.

Ocean outfalls consist of long pipelines which carry the effluent through the "surf-zone," generally terminating in diffuser sections used to mix and dilute the light-weight effluent with the heavy ocean water.

Long and deep outfalls terminating in well-designed diffuser sections can, where the ocean is stratified, be used to avoid any noticeable surfacing or "beaching" of the effluent. Outfalls of such design are generally very costly, greatly restricting their use by food processors. Less extensive outfalls, discharging nearer the ocean surface, create wastewater fields. The fields are formed by the mixed effluent and adjacent ocean water rising to the surface. The movement of the field is at the dictates of ocean currents.

Design of ocean outfalls requires extensive knowledge of mixing and diffusion sciences, oceanology, and marine engineering. Just constructing a pipeline through the active surf-zone is a formidable task. A specialized technical discipline has evolved around study, location, design, and construction of ocean outfalls. These specialists must be used to realize any hope for installation of a successful ocean outfall. These same specialists can help in dealing with the complex public/environmental issues which are associated with constructing such outfalls.

4.44 Land

Disposal to land implies land treatment. Indeed, the terms land treatment and land disposal are used synonymously. Section 4.3 describes and presents design information on land treatment. Information presented in Section 4.3 is fully pertinent to any discussion of land's potential benefit in effluent disposal.

Land, obviously, is never the final recipient of wastewater – it is an intermediate. Most of the pollutants and, depending upon design and wastewater effluent loadings, most of the nutrients are removed by the natural processes associated with the soil and cover crop. The water itself enters the groundwater system via percolation, the atmosphere via evapotranspiration, and adjacent surface waters by overland flow. The relative percentage of applied water entering each of these three receivers is dependent upon land conditions and design – these variables are described in Section 4.3.

A feature unique to land disposal is that an NPDES permit is not required. This does not mean land disposal is without regulation. Indeed, most states regulate land treatment and disposal closely. Requirements, including pretreatment requirements, are highly varied, and state regulatory and local agencies should first be contacted before proceeding with planning for land disposal.

4.45 Public Sewers

4.451 GENERAL

Discharge to public sewers may be a regulatory agency requirement if the discharger is in a sewer service area, or such a discharge may be the simplest and least costly method for dealing with a food processing wastewater. Discharge to public sewers always requires at least some degree of pretreatment. Section 4.1 describes pretreatment requirements and available pretreatment processes and devices.

Discharge to a public sewer transfers the primary responsibility for treating the wastewater to an agency or municipal department whose sole purpose is wastewater treatment, as opposed to the processor seeking to optimize production. Inclusion of industrial users in the planning for public sewerage systems is a requirement of most governmental funding agencies.

Some of the factors favoring and opposing joint treatment of food processing and domestic wastewater are as follows.

Factors favoring joint treatment include:

- Nutrients from domestic sewage are available to nutrient deficient food processing wastewaters.
- Food processing wastewater loads are leveled.
- Annual treatment plant startup problems and inefficiencies are eliminated.
- The treatment system can be operated continuously.
- Qualified operators are available.
- Food processors will not pay property taxes on a treatment system since they do not own the system.
- Food processors will not be required to acquire and invest capital in their own treatment system.
- Food processors' property is not required for construction of the treatment units.
- Economy of scale reduces costs.

Factors opposing joint treatment include:

- Any possibility for recovering usable products is lost when the wastewater is mixed with sewage.
- The types of treatment which can be used for a composite wastewater are limited.
- The food processor may have to be inside the taxing district.
- Public agencies use higher standards of construction; consequently, construction costs are higher than industrial construction. Public agencies are also required to provide standby and redundant units because the system must accept and treat sewage at all times; consequently, the unit costs are higher than the comparable industrial plants.
- Public agencies spend more on operating costs than industries. Food processors can use maintenance staff from the processing plant.
- Food processors will give up some independence to join with the public agency.
- Ordinances and rate schedules may make a substantial degree of pretreatment necessary. Stringent effluent discharge limitations may be reflected in the industrial sewer ordinance.

4.452 INDUSTRIAL SEWER SERVICE CHARGES

All public agencies charge for the use of their sewers and treatment plants. The base and amounts of charges will vary from locale to locale. At present in the U.S., the Environmental Protection Agency or the State Water Quality Control Agency sets specific guidelines concerning acceptable rate structures. The most common basis for distributing costs is a rate structure based on BOD, suspended solids, and flow. The rate structure used must be considered a fair-share approach. Everyone using the system must pay their share in proportion to use.

Sources of income used to finance public treatment plants in the past have included taxes, sewer service charges, and assessments. EPA has decreed that taxes no longer be used. In general, industry is not required to pay for reserve capacity for future loads. Industry only pays for the amount of treatment capacity they use each year, unless the industry requests reserve capacity.

The general administrative overheads which may accrue to the sewer system and treatment plant may be excluded from the rate distribution. Only those costs which are a result of operating and maintaining the treatment plant are distributed to industries in the usual case.

The best way to explain how a rate structure is developed is to use an example. The following example employs some simplifying assumptions so that the basic approach can be illustrated. Some of these assumptions are as follows:

- A conventional secondary treatment plant is used. This plant is a simple, activated sludge plant with the units as indicated in Figure 4.27.
- The load to the treatment plant is as follows:

	Industrial	Domestic/ Commercial
Flow	50%	50%
BOD	75%	25%
Suspended solids	30%	70%

- There is no reserve capacity and the plant is not overloaded. In other words, the plant is serving exactly the load for which it was designed (a rare occurrence).
- The industrial loads are continuous and uniform throughout the year (a rare occurrence for food processors).
- Industries will pay for their share of a 75 percent EPA grant over a 30-year period making the annual payment 1/30 of the grant amount. Thirty years is the maximum period allowed by EPA in grant repayment.
- Industries will pay for their share of the capital cost raised by the public agency on the basis of the cost of the money to the public agency (not an EPA requirement).
- No local taxes are used to fund the system (an EPA requirement).
- Industries will pay only a share of the treatment system O&M costs (EPA requires a sharing of O&M costs).

The rate structure is used to distribute both capital costs and operating and maintenance costs.

The capital costs can be distributed by breaking the treatment system into individual units as shown in Table 4.20. During the planning process, these costs are based on engineering estimates. The actual rates should be based on construction contracts.

Each unit within the treatment plant is designed for one or more wastewater characteristics. In this case, the simplifying assumption is made that each unit is designed for only one wastewater characteristic, as shown in Table 4.20. The total costs of the treatment plant which are caused by flow, BOD

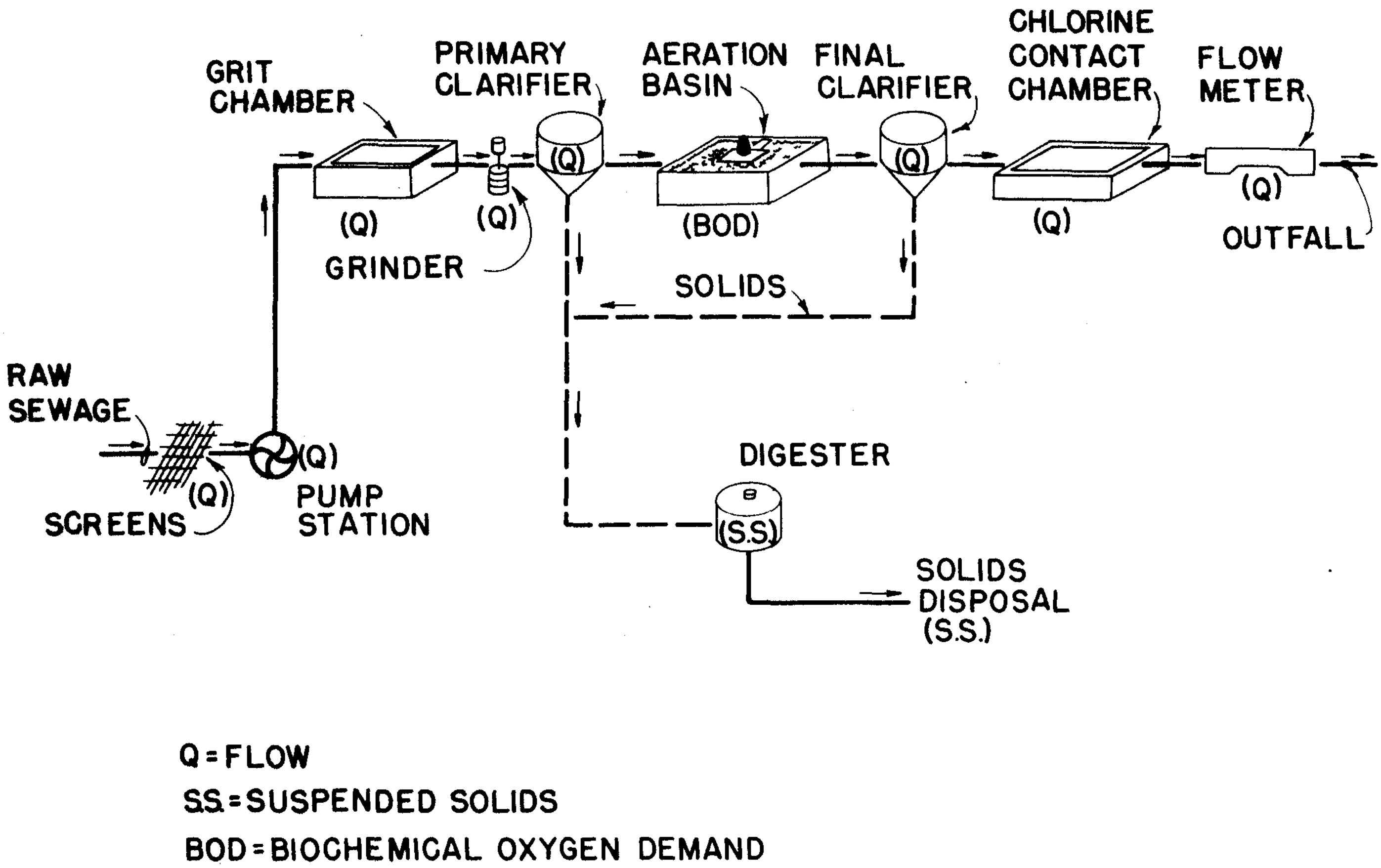


Figure 4.27. Joint treatment plant cost allocation.

TABLE 4.20
JOINT TREATMENT CAPITAL COST DISTRIBUTION

Unit	Characteristic For Which Designed	Total Cost Of Unit	Cost For: Flow	Cost For: BOD	Cost For: S.S.
Bar Screen	Flow	$ 20,000	$ 20,000		
Pump Station	Flow	60,000	60,000		
Grit Chamber	Flow	20,000	20,000		
Grinders	Flow	20,000	20,000		
Primary Clarifier	Flow	100,000	100,000		
Aeration Basin	BOD	200,000		$200,000	
Secondary Clarifier	Flow	100,000	100,000		
Chlorine Contact Chamber	Flow	40,000	40,000		
Sewage Piping	Flow	20,000	20,000		
Sludge Piping	Suspended Solids	20,000			$ 20,000
Digesters	Suspended Solids	100,000			100,000
Sludge Disposal System	Suspended Solids	60,000			60,000
TOTAL →		$760,000			
TOTAL PER CHARACTERISTIC →			$380,000	$200,000	$180,000
% OF TOTAL COST →			50%	26%	24%
% TO INDUSTRY →			50%	75%	30%
CAPITAL INVESTMENT FOR INDUSTRY →			$190,000	$150,000	$ 54,000
SUBTOTAL →					$394,000
75% EPA GRANT →					$295,500
CITY COST APPLIED TO INDUSTRIAL RATES (25%) →					$ 98,500
EPA CAPITAL COST RECOVERY (1/30 x $295,500) →					$ 9,850/yr
20-YEAR BOND AT 5% ANNUAL P&I ($98,500 x 0.0802) →					$ 7,900/yr
TOTAL CAPITAL COST TO INDUSTRY					$ 17,750/yr

TABLE 4.21

JOINT TREATMENT
O&M COST DISTRIBUTION

	Cost	Flow		BOD		Suspended Solids	
		%	$	%	$	%	$
Labor	$29,000	50%	$14,500	26%	$ 7,500	24%	$7,000
Equipment Repair	3,000	50	1,500	26	780	24	720
Chlorine	4,000	100	4,000				
Power	10,000	45	4,500	50	5,000	5	500
Supplies	3,000	50	1,500	26	780	24	720
Sludge Disposal	1,000					100	1,000
TOTAL	$50,000		$26,000		$14,060		$9,940
Industry's Annual Share, By Parameter		50% —	$13,000	75% —	$10,500	30% —	$3,000
INDUSTRY'S TOTAL ANNUAL SHARE →					$26,500		

and suspended solids are shown at the bottom of this table. These costs are then distributed to industries in proportion to their use.

The costs which would be borne by industries for the 75 percent EPA loan would be $9,850 per year if the loan is repaid in a 30-year period. A portion of the plant capital costs financed by the public agency is commonly repaid over the life of the bond issue at the actual bond interest rate. In this case a 5 percent interest rate is assumed on a 20-year issue. The yearly cost to industry would be $7,900. The combination of the capital costs, as a result of the EPA loan and the public agency's bonds for industry, would be $17,750 per year.

Operating and maintenance costs are similarly determined. Note that in Table 4.20, 50 percent of the plant costs resulted from flow-related items, 26 percent of the plant costs from BOD-related items, and 24 percent from suspended solids-related items. Table 4.21 lists the estimated operating costs for the plant. Some of these costs, such as power, can be related to BOD, suspended solids, or flow, by computing the actual energy used in each unit. Other items, such as labor, are best distributed based on the capital cost breakdown in the plant as shown in Table 4.20. The total cost to industry for operation and maintenance would be $26,500 in this example.

The total annual cost to industry would be the sum of capital costs and operating and maintenance costs. In this example the total is $44,250 ($17,750 + $26,500).

If there is more than one industrial contributor, the distribution to each industry is made by multiplying the total industrial charge by the individual industry's fractional use of the system.

4.453 ORDINANCES AND RESOLUTIONS

Following agreement between the food processor and the serving public agency on the many facets of joint treatment, it is necessary to transform this information into written documents, ordinances, resolutions, and contracts.

The method of sampling, testing, rate computations, and payment of user charges should be referenced in an ordinance. The sewer user ordinance is also necessary to establish limits on the discharge to the sewer and treatment system (see Sections 4.03 and 4.101). The essence of such ordinances is to protect the sewer system from physical damage or stoppage, protection of the treatment unit from damage or process upset, and protection of the receiving waters.

These ordinances should be no more restrictive than necessary and should allow for flexibility to accommodate future changes, particularly in the processor's quantity and character of wastewater.

4.5

SOLIDS CONDITIONING AND DISPOSAL

4.51 Sources and Nature of Solids

Because of the nature of fruits and vegetables, a great many solids are generated during processing. These solids, or "residuals," may exceed the mass of solids generated by treatment of the effluent. The sources, quantities, and disposal methods for these materials are discussed in Section 1.23.

The handling and disposal of the in-plant wastewater treatment generated solids or sludges vary not only with the characteristic of each, but also with the governmental classification of the solids. Currently, transportation and final disposal of waste solids from wastewater treatment plants are more closely regulated than waste solids from food processing.

Depending on the processes used and the extent of treatment, solids generated in wastewater treatment can be quite significant. Table 4.22 lists the types of treatment and the characteristics of the general types of solids produced. Two main categories are screenings and sludges. Sludges are generated in primary, secondary, and, to a minor extent, tertiary treatment processes.

TABLE 4.22
TREATMENT PLANT SOLIDS CHARACTERISTICS
FRUIT AND VEGETABLE WASTEWATERS

Type of Treatment	Sludge Characteristic
Primary	Percent solids: 1-5%. A higher percentage of silt in the sludge can raise the percentage of solids to 20-40%.
Biological Sludge	0.5-1% solids from the clarifier underflow.
Pure-Oxygen Activated Sludge	1-2% solids.
Lime Clarifier Sludge (Tertiary)	7% solids.

4.511 SCREENINGS

The amount of screenings vary according to the nature of the wastewater and screen mesh size. Screenings are wet and will drain if allowed to stand. Draining the water does not reduce the volume of screenings to be hauled away, but makes them easier to handle and more acceptable in landfill sites.

4.512 PRIMARY TREATMENT SLUDGE

This category includes sludge removed from the bottom of clarifiers, scum from the top of clarifiers, and float from the top of dissolved-air flotation units.

Dissolved-air flotation float commonly has a total solids concentration of about 4 to 6 percent and is not difficult to pump. Sludge from the bottom of clarifiers can be very difficult to pump depending on the product being run. For example, field dirt from tomatoes and potatoes can be thickened to about 40 percent solids which can then be pumped, but only with positive displacement pumps. This same mud will only settle and concentrate to about 20 percent solids in a tank or pond without a thickening rake. An organic sludge from a primary clarifier will probably not exceed a concentration of 3 to 5 percent solids.

The actual mass (pounds per day) of sludge or float from primary treatment will be a function of the raw product. The volume (gallons per day) will be a function of both the product run and the primary treatment process used.

4.513 SECONDARY TREATMENT SLUDGE

The masses of sludges from the secondary treatment processes are a result of the process used, the BOD load, and the inert suspended solids load. The biological processes used in secondary treatment all produce sludge.

In biological treatment dissolved BOD is transformed into microorganism cellular matter, which then settles in the secondary clarifier. The largest sludge producing processes are the high-rate processes described in Section 4.2. Of these, the activated sludge process produces the most sludge.

Stabilization ponds and aerated ponds accumulate sludge on the bottom of the ponds.

Activated sludge plants treating food processing wastewater generally produce 0.3 to 0.6 pounds of microorganisms for each pound of BOD removed. Sludge from secondary treatment systems is still biologically active and will putrefy. This can cause an intolerable odor. If the sludge contains no domestic wastes, it may be possible to spread and dry the sludge quickly on a disposal site or agricultural land, and then plow it into the soil. If the sludge is not plowed into the soil, it must be treated to stabilize the remaining organics before applying it to land.

Secondary sludge is difficult to dewater. Most raw, undigested secondary sludges have total solids concentrations of only one-half to one percent. In addition the cellular matter in the sludge is only about 15 percent solids. Unless the cell membranes are ruptured, microorganisms cannot be dewatered to greater than 10 percent solids. Cells can be ruptured by heating or slow freezing. Natural freezing can be used in some climates. Commercially available heat treatment systems are costly and have not been used in the food processing industry.

4.514 TERTIARY TREATMENT SLUDGES AND CONCENTRATES

With the exception of chemical clarification, none of the tertiary treatment processes discussed earlier generate a solid waste. Reverse osmosis and ion exchange produce a waste brine or concentrate, which is probably best handled by evaporation and disposal in a landfill. Spent carbon in column, if not regenerated, becomes a solid waste, but it is usually acceptable for disposal in a sanitary landfill. Backwash water from filters is usually stored and pumped at a constant rate back to the treatment plant headworks.

Sludge from tertiary chemical clarifiers varies in handling characteristics according to the coagulants used in the treatment process. Lime sludge is quite dense, about 7 percent solids, and can be dewatered rather well with vacuum filters or centrifuges. Lime sludge lines should be oversized to allow for scaling in the lines and cleaning. Alum sludge, however, is quite light, gelatinous, and difficult to dewater. Ferric chloride sludges are usually not difficult to dewater, but they are messy. Vacuum filters are usually used on ferric sludges.

Unless a secondary plant is upset, tertiary chemical clarifier sludge will contain few organics so further stabilizing the sludge to prevent putrefaction is not necessary.

4.515 SLUDGE HANDLING

Table 4.23 lists the available options most commonly used in handling wastewater treatment plant sludges.

Treatment and disposal of wastewater treatment solids require a substantial fraction of the cost of treatment (Tables 4.10 and 4.11).

TABLE 4.23
SOLIDS HANDLING OPTIONS

Digestion	Thickening	Dewatering	Disposal
Anaerobic	Gravity	Vacuum Filter	Sanitary Landfill
Aerobic	Dissolved Air Flotation	Centrifuge	Disposal on Soil
	Centrifuge	Pressure Filter	Animal Feeding*
		Dewatering Belts	Composting
		Drying Beds	

*Use of waste activate sludge for animal feeding operation is not generally approved by the U.S. Food and Drug Administration

4.52 Digestion

There are two types of biological sludge digestion processes: anaerobic and aerobic. Anaerobic digestion has been practiced for many years at municipal treatment plants across the country. Anaerobic systems are prone to upset and must be heated to 90 to 100 degrees Fahrenheit (F) and the temperature held constant for good operation. The tanks must be covered to collect the generated gas. The gas usually contains about 65 percent methane and can be used as a fuel. The tank contents must be well mixed.

A well-operating anaerobic digester will destroy about 45 to 60 percent of the volatile or organic fraction in the sludge. It operates well on domestic primary sludge alone. Few food processing sludges have been digested alone. The required retention time of sludge in a well mixed digester is 10 to 30 days when maintained at a constant temperature greater than 90 degrees F but less than 100 degrees F.

Aerobic digestion is more practical than anaerobic digestion for seasonally operated plants treating only food processing wastewater. Aerobic digestion allows the metabolic processes of the micro-organisms used in treatment to continue, but in the absence of food (BOD). The organisms continue metabolizing at decreasing rates (termed "endogenous respiration") in the digester. Aerobic digestion will reduce the organic content of sludge up to 40 percent. Detention times of the sludge in aerobic digestion is 10 to 20 days. Enough air is supplied to the open digester, either by diffusion or mechanical means, to satisfy the oxygen requirements of the organisms.

Regardless of the method of digestion chosen, the digester must be kept operating after the end of the processing season to stabilize the remaining sludge.

4.53 Thickening and Dewatering

4.531 THICKENERS

Thickening is used to reduce the volume of sludge so a smaller dewatering device can be used, or to control sludge thickness for optimal operation of the dewatering devices.

Three units are commonly used for thickening sludge: gravity thickeners, flotation thickeners, and centrifuges.

Flotation thickeners are the same as air-flotation clarifiers but operated at higher solids loading rates. Gravity thickeners look like ordinary clarifiers except the clarifier rake is rotated faster to convey and agitate the sludge blanket. Representative design criteria for thickeners are given in Table 4.24.

TABLE 4.24
DESIGN CRITERIA SOLIDS HANDLING DEVICES
FRUIT AND VEGETABLE WASTEWATERS

DIGESTION	
ANAEROBIC	
Retention Time	10 - 30 days, depending on the digester heating and mixing design
Ideal Temperature	90 - 100°F
Volatile Solids Reduction	45 - 60%
Methane Production	8 - 12 cf/lb volatile solids destroyed.
Solids Loading	Standard Rate: 0.03 - 0.10 lb volatile solids/cf/day High Rate: 0.1 - 0.4 lb volatile solids/cf/day
AEROBIC	
Retention Time	10 - 20 days, depending on the sludge age of the activated sludge system and the ambient temperature
Solids Loading	0.1 - 0.2 lb volatile solids/cf/day
Oxygen Requirement	1.5 - 2.0 lbs/lb of volatile solids destroyed
Volatile Solids Reduction	up to 40%
THICKENING	
GRAVITY	
Solids Loading	4 - 15 lbs solids/sf/day, depending on the concentration of the incoming sludge
Overflow Rates	400 - 900 gpd/sf
DISSOLVED-AIR FLOTATION	
Solids Loading	1.5 - 2 lbs/sf/hour
Overflow Rates	1,400-5,000 gpd/sf
HPO Sludge	3 lbs/sf/hour
Air-to-Solids Ratio	0.01 - 0.1 lb/lb
Recycle Rate	50 - 80%
Pressure	60 - 70 psi
DEWATERING	
VACUUM FILTERS	
Common Yields	1 - 4 lbs of dry solids/hr/sf of drum for organic primary sludge 8 - 10 lbs/hr/sf for properly conditioned silt and clay
Cake Total Solids Content	11 - 13% for primary sludge 20 - 70% for silt or clay. Not applicable for biological sludges
Solids Capture	85 - 95%
CENTRIFUGES	
Cake Total Solids Content	For primary sludge 4 - 25%, depending on the use of chemicals and type of centrifuge. For waste activated sludge: Solid bowl type: 6 - 10%, w/poly Disk nozzle type: 4 - 5%, w/o poly Basket Type: 7 - 10%, w/o poly; 9 - 12%, w/poly
Solids Capture	60 - 70% without chemicals up to 95% with chemicals
Common Capacities	10 - 300 gpm

Dewatering lowers water content of sludges to facilitate disposal, whether by landfill or by incineration. Before sludge can be hauled in open trucks, it should be dewatered so that it does not flow.

Several kinds of dewatering units are available. The most common are vacuum filters and centrifuges, but filter presses and capillary action devices may be used.

4.532 VACUUM FILTERS

A common type of vacuum filter is shown on Figure 4.28. The sludge is pumped into a vat or pan at the base of the filter. The sludge level is usually high enough to submerge the filter drum to about 30 to 40 percent of the diameter of the drum. A vacuum applied to the drum (about 10 to 20 inches of mercury) picks up the sludge and forms a cake during the time the drum is submerged. As the drum rotates out of the sludge, air is pulled through the sludge cake, drying it so it falls or can be scraped from the filter cloth.

The yield, or rate of sludge dewatering, of a vacuum filter is about one to ten pounds of dry sludge per hour for each square foot of filter drum area.

Most sludges must be conditioned with chemicals before they can be filtered. The addition of chemicals will usually increase the filter yield. A key to good filter operation is the solids concentration in the filter feed.

Vacuum filters have a high capital cost and are difficult to operate. Sometimes they require a full-time operator.

4.533 CENTRIFUGES

Three types of centrifuges are now commercially available. The solid bowl centrifuge (Figure 4.29) is more suitable for the dewatering of inorganic sludges. Disc nozzle (Figure 4.30) and basket centrifuges (Figure 4.31) seem to work better on organic sludges, but the disc nozzle type tends to clog at high concentrations of sludge or when proper sludge pretreatment (grit removal, screening) is not provided.

Several basket centrifuge installations are now operating on secondary sludge.

4.534 OTHER METHODS

Filter presses or pressure filters work well on some sludges. They are, however, quite expensive and can be difficult to operate and maintain.

About three different units on the market use a combination gravity and capillary action to dewater sludge. These units rely on a porous cloth to suck water from the sludge as it is squeezed between rollers. These units are easy to operate but have a low capacity. They cannot be universally applied to different sludges and appear to work best on waste activated sludges from domestic treatment plants.

4.535 SLUDGE DRYING BEDS AND LAGOONS

In areas with dry weather during the processing season, sludge drying beds and sludge lagoons may be effectively used to dewater digested sludge for disposal. Drying beds are constructed with sand bottoms and an underdrain system to capture water that percolates down through the sludge.

Digested sludge is pumped to each bed until the depth reaches about 18 inches, then new sludge is pumped to another bed. Water evaporates from the sludge surface and also percolates down through the bed. The drained water is returned to the treatment plant headworks. When sufficiently dry the sludge is taken out with a skip loader. As long as

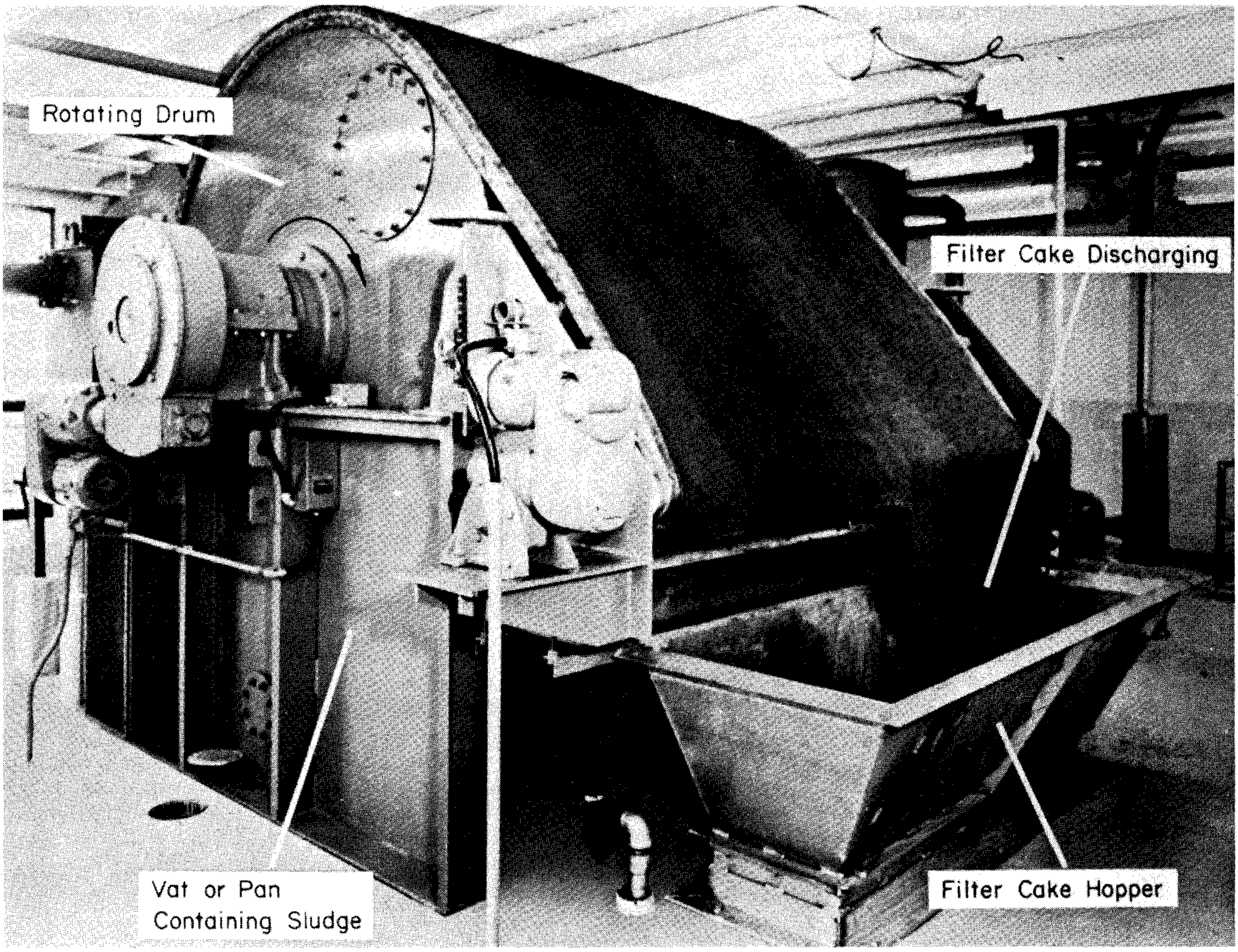


Figure 4.28. Vacuum filter.

the sludge is adequately digested, the drying beds will have only a slight musty odor.

Sludge lagoons differ from beds in that they are deeper (about two to three feet) and do not have a sand blanket with underdrains. If sufficiently dry the sludge may be taken out with a skip loader, otherwise it must be removed with a dragline or dredge.

4.54 Methods of Solids Disposal

The ultimate disposal of solids is becoming quite a problem. Most public treatment plants are now disposing of dewatered digested sludge in landfills. In-plant residuals from most food processing plants are disposed of in landfills usually owned by a public agency. As these sites are filled, food processors are often asked to go elsewhere with their residuals, screenings, and sludge.

Some food processors are now operating their own land disposal systems for residuals and treatment plant sludges (see Section 5.23).

Many food processors are able to dispose of some portion of the solid wastes, usually screenings, to animal feeding operations. Because of the relatively low-food value of most screenings, they must be mixed with grains or other common feed to provide a balanced diet for animals. Because of the specific dietary requirements of many animals and the variability of goals of feeding (egg versus meat production for poultry, for example), feeding requirements should be studied before starting such a program. As a rule the lack of complete nutrients in food processing wastewater, coupled with the seasonality of waste production, does not make the program attractive to animal feeders. Transportation costs also make this option unattractive. Year-round operations, like potato processing, have been successful in setting up operations with local feed lots to accept screenings and primary sludge.

4.541 LAND DISPOSAL OF WASTE SOLIDS

Residuals that are not converted to a by-product or animal feed are a major problem. Land disposal in some form

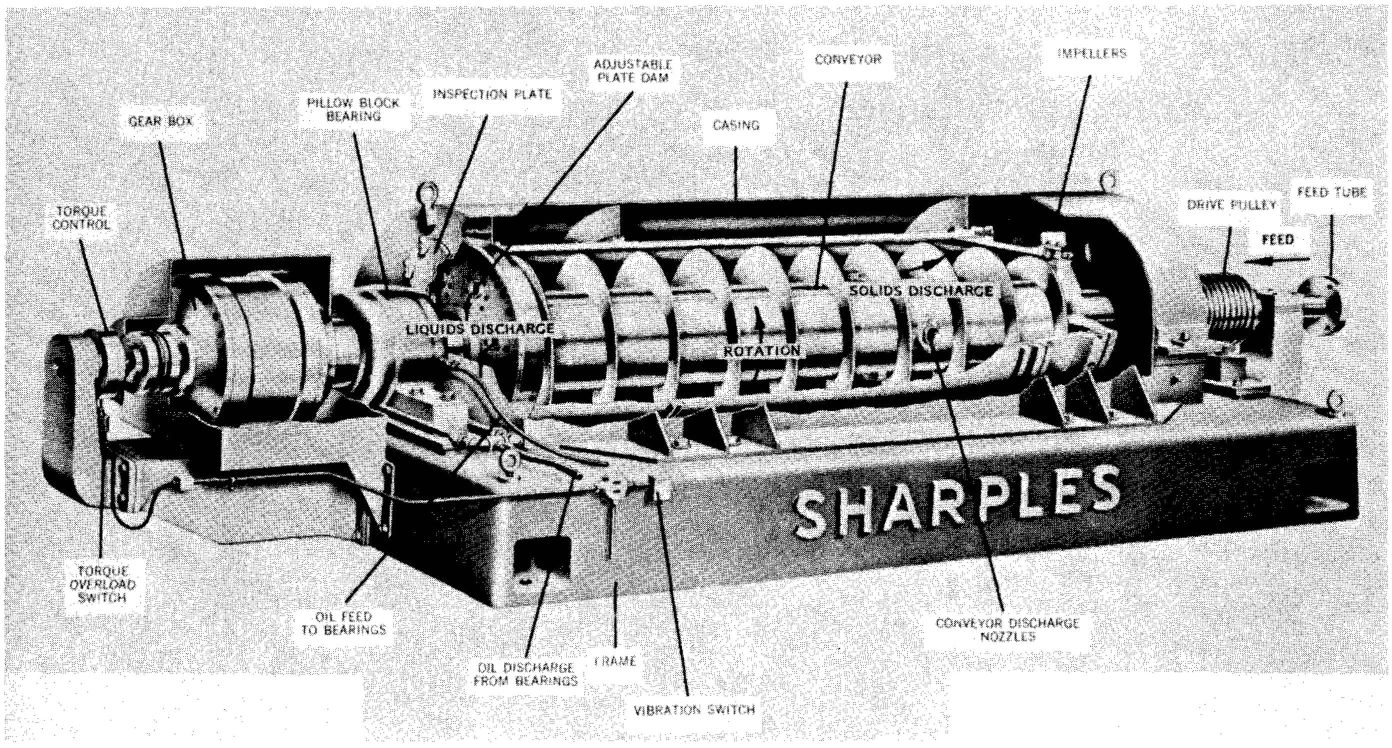


Figure 4.29. Solid bowl centrifuge.

is usually the only option. Local regulations on land disposal are becoming more stringent. Present practices should be carefully reviewed to avoid problems. In the future land disposal sites will have to be selected and operated with greater care. The following is a general discussion of the factors to consider.

Silt, screenings, primary treatment sludges, and other dry waste can usually either be incorporated in a landfill or tilled into the soil. However, sludges from secondary and advanced waste treatment will not be allowed in a landfill unless they are concentrated to a semi-solid. This conversion is usually too costly to be practical. Therefore, the usual option for disposal of dilute sludge is land spreading. The limits for application of food processing waste solids to land are much less defined than for irrigation of liquids.

Land application of waste solids can be grouped into two methods: (1) fertilizer, and (2) disposal. The fertilizer method maximizes crop production while using the waste solids for nutrients and soil conditioning. The loading rates are relatively low when compared to the disposal method. Any soils suitable for high-production agriculture will generally be suitable for application of waste solids. Clay soils or other soils with low-organic matter will receive special benefit from residuals. Loading rates are about three to ten tons of dry solids per acre per year.

The disposal method maximizes disposal by incorporating large amounts of the solids into the soil. This process is essentially a sanitary landfill. Most of these are now publicly owned and operated. A crop is maintained mainly to enhance site appearance, minimize wind erosion, take up moisture, or use some of the nutrients in the residuals. Loading rates are about 5 to 50 tons per acre per year. The leachate from landfills is a substantial problem. Leachate is odorous and high strength and must be irrigated or treated for discharge.

4.542 PRETREATMENT REQUIREMENTS

Waste solids vary greatly in character and pretreatment requirements, depending on the food being processed, method of processing, and method of treatment. Adjustment of the pH will be required before land application if it is much below 6.4 or above 8.4. These limits will vary, depending on the texture and buffering capacity of the soil and the loading rate. The solids may need to be stabilized by biological treatment so that rapid degradation and odor do not result when they are applied to land. The solids may need to be ground to allow better incorporation into the soil and better operation of application equipment. Dewatering of solids may be advantageous to a land disposal system. It will result in less volume handled and, possibly, a smaller disposal site.

4.543 APPLICATION AND INCORPORATION METHODS

Waste solids can be applied to land by several methods. As a liquid they can be injected or plowed under the surface, spread by truck or tractor, or sprayed. As a solid they can be spread by equipment such as manure spreaders. The selection of the suitable method depends upon soil characteristics, crop, labor requirements, maintenance, topography, and costs.

In general the solids must not be allowed to remain on the soil surface for a long time because of odor, insect, and wind and water erosion problems which often result. Insect problems may develop even when liquid waste solids are immediately incorporated into the soil. This has been prevented by spreading the solids in a thin layer and allow-

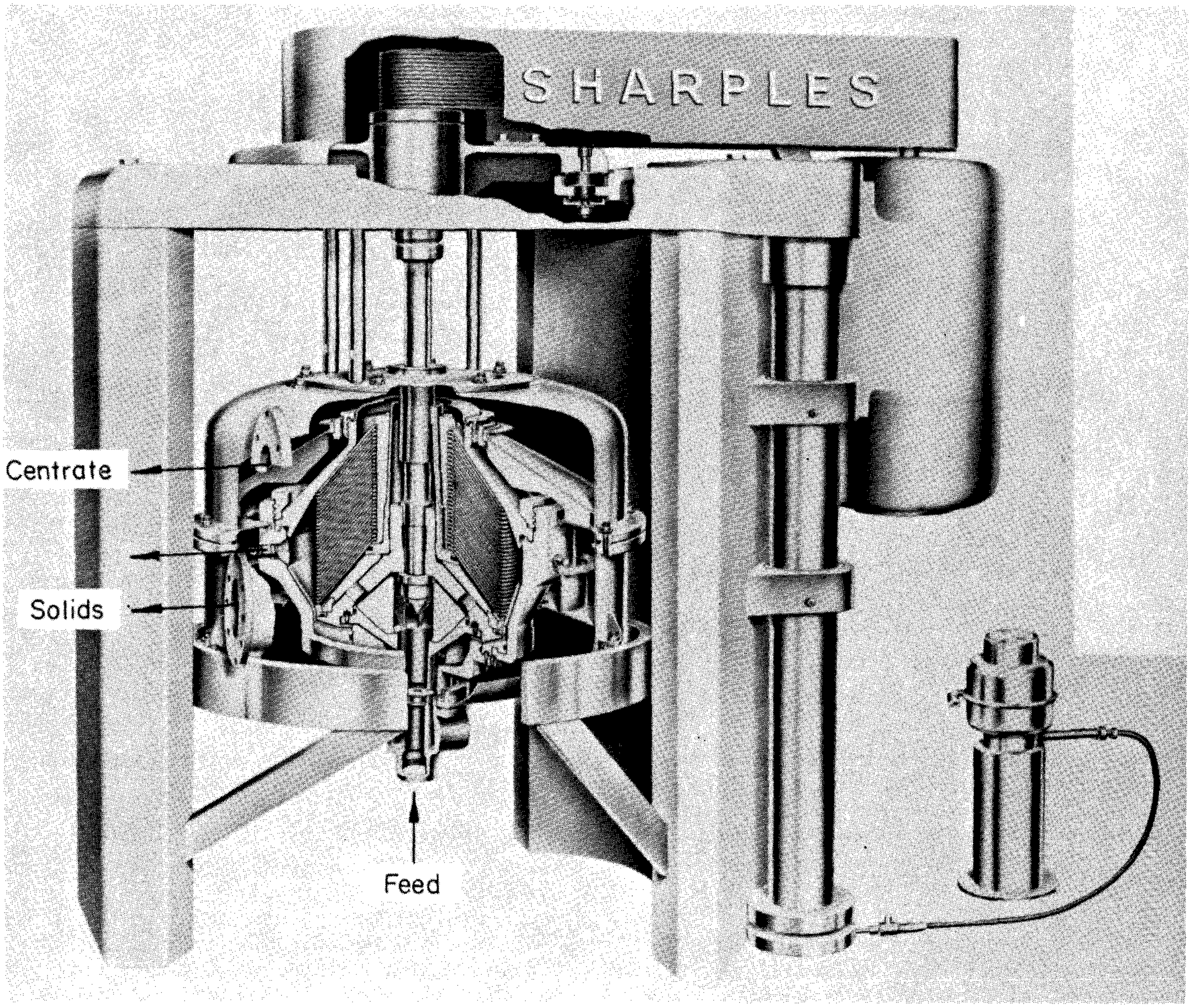


Figure 4.30. Disc nozzle centrifuge.

ing them to remain on the surface just long enough to dry before tilling into the soil.

4.544 SITE SELECTION CRITERIA

The criteria for site selection are generally the same as those listed for a land treatment site in Section 4.3, with the following exceptions:

- Hydraulic loading will not be as great; therefore, the subsurface permeability is not as important.
- Because of the appearance of solids and the nature of the operation, a remote or concealable site should be selected.

4.545 APPLICATION RATE CONSTRAINTS

The application rate will be limited by several constraints.

- Nutrient balances
- BOD
- Nitrogen
- Solids loading rate
- SAR (sodium adsorption ratio)
- pH

All of the above mentioned factors vary greatly between types of food processed and the method of processing and wastewater treatment. The loading rate must be studied carefully in each case. The hydraulic loading limits, infiltration capacity, root-zone permeability, and geologic permeability are not usually limiting because only small amounts of water will be applied with the solids. Solids must be incorporated into the soil as applied or very shortly thereafter. Limits exist on how much organic solids can be physically incorporated into the soil and on the soil's ability to decompose solids without causing plant toxicity problems. Limits on BOD, nitrogen, SAR, dissolved salts, etc. are approached the same as for land treatment discussed in Section 4.3.

4.546 MANAGEMENT AND OPERATION

Proper management and operation of a solids disposal system is as important as it is for a wastewater treatment and disposal system. A major factor for successful operation is the timing of land application.

In a fertilizer application system where crop production is optimized, waste solids cannot be applied and tilled into the soil while the crop is growing. Tillage would kill most crops. Cropping areas and disposal areas can be alternated. The method of disposal used – either fertilizer or disposal – will depend greatly on who owns the site and who operates the system. A farmer will want to maximize crop production, while a food processor will want to maximize residuals disposal. Other practices, such as crop and soil management and monitoring, are also important as noted in the discussion of land treatment.

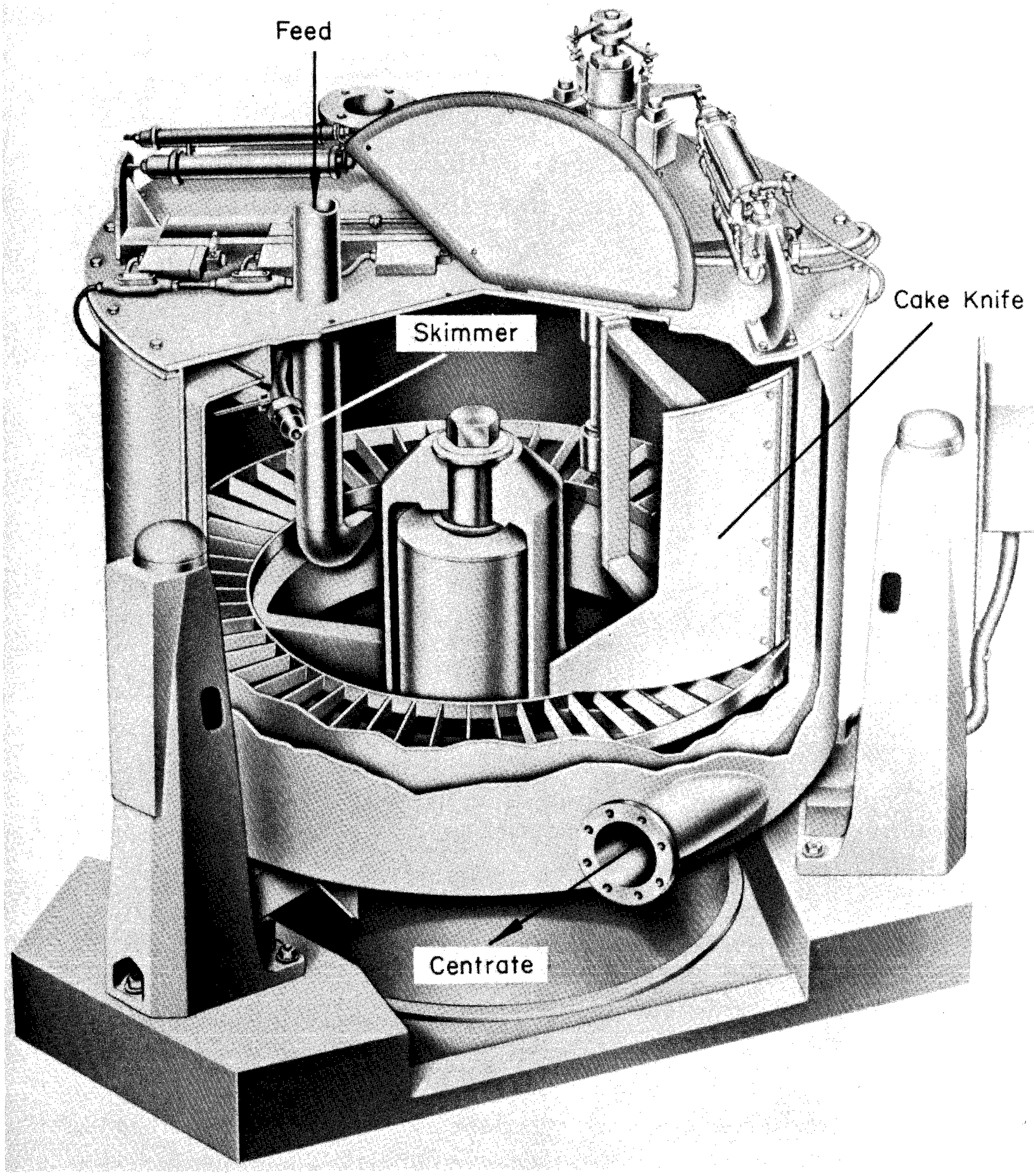


Figure 4.31. Basket centrifuge.

4.547 COST OF RESIDUALS DELIVERY AND APPLICATION

The cost of disposing of residuals onto land can vary greatly depending on the amount of liquid in the residuals, the distance to be transported, and the method of delivery and application. Some typical recent costs for hauling are given in Table 4.25. Actual costs vary considerably due to differences in disposal sites, government regulations, availability of trucking firms, and pretreatment requirements. The costs given in the Table do not include pretreatment or site preparation costs.

TABLE 4.25

COST RANGES OF HAULING AND DISPOSAL

Hauling of Liquid Sludge (4 - 15% TS) to Ponding Site (20 mi haul)	4 - 5 cents/gallon— includes disposal fee of 3-1/2 cents/gallon
Hauling of Liquid Sludge (4% TS) to Farm Land (35 mi haul)	2 cents/gallon or $3.70/ton-mile
Hauling of Screenings, Mud to Land Fill	$4.00/cubic yard — includes disposal fee of $1.00/cubic yard
Hauling, Spreading of Dewatered Sludge to Disposal Site (5 mi haul)	$1 — $2/ton-mile
Hauling, Spreading of Liquid Sludge to Disposal Site (5 mi haul)	$3 - $4/ton-mile
Hauling of Hazardous Waste (acid, caustic) to Evaporation Ponds	8 - 10 cents/gallon— includes disposal fee

4.6

POTENTIAL OPERATING PROBLEMS

Numerous potential problems exist which will compromise treatment system operation, performance and community acceptance, if not properly addressed in wastewater treatment system design and operation. Among these potential problems are the following:

- Odor
- Freezing
- Wind Drift and Fogging
- Coloration
- Floating Solids
- Bulking Sludge
- Vector Propagation
- Changing Wastewater Quantity and Character

Each of the foregoing is briefly discussed in this Section.

4.61 Odor

Odors in wastewater treatment are associated almost exclusively with wastewater or sludge septicity. Release of hydrogen sulfide and other malodorous gases was alluded to in Section 4.232. Prevention or control of odor is by no means a simple matter; however, it is best to follow these simple rules where possible:

1. Maintain minimum dissolved oxygen levels in aerobic system at 2.0 mg/l.
2. Enclose all anaerobic systems, collecting and burning off gas.
3. Minimize storage time of solid residuals and undigested sludges, limiting on-site storage to one shift or less prior to disposal or by-product utilization.

Odor release from wastewater can be controlled by addition of chlorine (up to 20 mg/l), ozone or, where detention time and mixing is sufficient, air or oxygen. Chlorine and ozone can be effective in disinfecting wastewaters as well as oxidizing the odor sources.

Odorous vent gases or anaerobic process off-gasses may be controlled by flaring, ozone oxidation, masking the odor with aerosols, or adsorption of the odor onto activated carbon. Selection of a control technique should be preceded by pilot testing as the effectiveness of each potential control technique will vary with the specific chemical odor compounds being oxidized, adsorbed, or otherwise controlled.

Improper operation of clarifiers can produce odor problems easily solved by operating changes. The point here is to not use clarifiers as solids storage devices unless associated odor releases and other potential problems can be tolerated. It is best to maintain clarifier sludge blankets at low levels near the bottom cone.

Controlling odors from sludge lagoons or drying beds receiving poorly digested or undigested sludge can be a real problem. Liming the sludge to pH 10 or greater can be effective. Fogging of aerosols has occasionally been successful.

Where odor release from wastewater treatment or sludge disposal operations is anticipated, facilities location becomes of paramount importance. There will be few complaints if odor releases are sufficiently isolated from people. Where there are neighbors (true in most cases), try to locate in the prevailing downwind direction.

Odor control in land treatment of wastewater is discussed in Section 4.3.

4.62 Freezing

Freezing or cold weather conditions have two potential adverse impacts on wastewater treatment. These are: (1) the slowing of microbial metabolism, the essence of secondary treatment, and (2) icing and its associated interference with operation of the physical treatment components. The impact of temperature on secondary biological treatment efficiency is described in Section 4.2323.

Ice formation in exposed pipes can be avoided by applying heat tracing tape and insulation. This same approach can be used to avoid ice buildup on the liquid side of steel clarifier and thickener tanks. Ice buildup on the liquid side of concrete tank walls is best avoided by tank burial. Ice buildup on the liquid side of clarifiers and thickeners not only lowers the wastewater temperature (an undesirable effect if secondary treatment is involved), the ice may stop mechanism rotation. Thawing a clarifier or thickener to loosen the mechanism is no small task.

Buried piping in land treatment systems exposed to deep frost penetration is generally protected by draining pipes not in use. Automatic valves, power or hydraulically activated, are sometimes used here. Care must be used in design to assure adequate capacity of any such drainage system, especially that of any leaching pits used to receive the drainage.

Mechanical aeration devices used in secondary treatment need to be selected with knowledge of potential icing problems. Ice buildup on liquid sensitive aerators will increase submergence and, thus, power draw. Sufficient icing of such floating aerators will result in overload and automatic shutdown. High-speed, floating aerators, such as depicted on Figure 4.13, are not liquid sensitive. Icing can still be a problem with these units, particularly icing under wind conditions. Here ice may build up on the windward side of the aerator drive and float, resulting in aerator overturn. Heat shrouds, or covers, designed to fit over high-speed aerator drives are available to mitigate this problem.

Ice shields are also available for mounting above fixed, low speed aerator devices. These shields are used to keep splash and ice formation away from aerator drives and access bridges.

Design provisions to avoid cold weather problems in clarifier-skimmer troughs and associated piping are discussed in Section 4.115.

4.63 Wind Drift and Fogging

Wind drift of mist is not generally a problem in wastewater treatment. Exceptions include wind drift from spray application to land treatment and mechanically aerated activated sludge aeration basins. Generally, a buffer zone of 200 to 300 feet width is adequate to avoid wind drift of aerator and spray generated mist to adjacent property. Many state regulatory agencies establish facilities setback criteria with an eye to avoiding wind drift problems to adjacent property.

Fogging is a potentially greater problem than wind drift. Fogging may extend for hundreds of feed downwind from the source. Wastewater treatment – sprinkling, aerating, spreading, or free surface containment of warm wastewaters – can be an excellent fogging source. Under proper atmospheric conditions (cool and humid) the water is lost to the atmosphere at the liquid-air interface. Th air cools once away from the warm wastewater, the moisture condenses, and fog results. Fogging becomes a critical problem when wind movement carries it to public areas, particularly roadways. There have been numerous fatal accidents caused by industrial fogging of public highways. The only good solution to the potential fogging problem is proper facilities location, giving consideration to adjacent property uses and limits. Care must be given to study of wind direction. The extent of moisture release and distance and degree of fogging needs to be anticipated.

4.64 Coloration

Some food processing effluents will be colored even after a high degree of secondary treatment. Table beet effluents are particularly troublesome in this regard. The highly nonbiodegradable color persists even after BOD satisfaction and suspended solids are removed. Such dissolved color substances can be removed by activated carbon adsorption, generally oxidized by ozone, and occasionally diminished or removed by chemical treatment. Such treatment is discussed in Section 4.24. These treatment solutions are costly. A strong case can be made that such treatment, solely or principally for color removal, is not cost effective. That is, the environmental damage in making and regenerating carbon, producing materials for constructing the contactors, and the consumption of energy associated with these activities do far more environmental damage than does the natural food-based color in the receiving water. Such cases should be made with regulatory agencies before treatment facility design, however, not after operation is started and the public and regulatory people are "surprised" that the effluent is still colored.

4.65 Floating Solids

The following discussion covers only the flotation of solids in wastewater treatment facilities where solids flotation is not desired. Examples are stabilization ponds and secondary clarifiers. The cause is gas generation in bottom solids, with the gas attaching to the bottom solids, lifting the solids to the surface much as occurs by design in air flotation devices (see Section 4.222).

Floating solids discharged from pond systems and clarifiers add to effluent suspended solids and BOD levels. For this reason pond outlets should be baffled or submerged. Clarifiers can be baffled and equipped with skimming devices. Care in operating clarifiers to avoid heavy solids buildup and septicity will greatly decrease the incidence of floating sludge problems.

Odor emissions invariably accompany floating solids problems. See Section 4.61 for a discussion of odor prevention and control.

4.66 Bulking Sludge

Sludge bulking is perhaps the greatest threat to successful operation of most activated sludge treatment plants in the food processing industry. The cause, excessive growth of filamentous microorganisms in the activated sludge, is discussed in Section 4.23.

Section 4.23 presents various design and operating parameters which, if strictly adhered to, will generally avoid bulking problems. Where bulking does occur, threatening process continuity, quick remedial action is called for. The conventional and probably most cost effective remedy is chlorination of either the aeration basin effluent (secondary clarifier influent) or the pumped sludge recycle. In either case the chlorine dosage should be on a mass activated sludge solids flow basis.

That is, chlorine at 0.1 to 1.0 percent by weight of the activated sludge should be added. For example, assuming a 0.3 percent dosage to a recycle sludge of 7,000 mg/l, the chlorine feed would be set at 21 mg/l. Lower dosages over extended periods of time (several days to a week or more) are preferred over higher dosages over short periods. High dosages show less discrimination for the filamentous microorganisms, killing a large percentage of the desirable microorganisms as well. The result can be a very turbid effluent containing high BOD and suspended solids levels. Chlorine dosages of less than 0.3 to 0.4 percent are somewhat more discriminatory. Hydrogen peroxide is even more specific against filamentous microorganisms. This oxidant has been very successful when used to rid an activated sludge system of bulking problems. The cost of hydrogen peroxide greatly restricts its use, however.

While chlorine and hydrogen peroxide can give temporary relief to bulking sludge problems, permanent relief is only obtained by proper system selection, design, and operation.

4.67 Vector Propagation

Wastewater treatment, waste solids conditioning and disposal offer opportunities for propagation of various vectors. Vectors of principal concern are flies, mosquitos, and rodents.

Flies are attracted to decaying, moist organic matter. Not only do they find it a choice foodstuff, it also is a prime breeding place. Controlling flies around a wastewater treatment plant is a matter of good housekeeping and avoiding on-site storage of undigested residual solids or sludges. Any stored sludges or residual solids which emit odor will likely create a fly problem. Insecticides should be used around solids bins and around sumps and other facility components through which wastewater is not continuously flowing. Where solids are buried or landfilled, at least 2 feet of cover should be provided.

Mosquitos, unlike flies, breed in standing water. Weeds, grass, etc., offer habitat to the adults. Eliminate standing water and you eliminate the mosquito. This is difficult where ponds are concerned. Land treatment systems must be constructed without "low spots" or "pockets" as these are especially suited to mosquito propagation. Catch basins and out-of-service tanks, channels, pipes, etc., serve as mosquito breeding places in treatment plants.

Where standing water cannot be eliminated, spraying breeding areas with insecticides and cutting and removing weeds and grasses growing in and adjacent to standing water are necessary.

Rats and mice are controlled in much the same way as are flies – good housekeeping and rapid removal of undigested organic matter to off-site disposal or by-product utilization. Elevated steel column-supported solids storage bins, concrete floors and above-grade construction discourages rodent infestation.

4.68 Changing Wastewater Quantity and Character

Major and permanent wastewater changes which result in treatment plant overload can only be accommodated by treatment capacity increases. Such occurrences are beyond the scope of this discussion. Of concern here are the changes which accompany pack changes and, to an even greater degree, beginning of season start-up and end of season shut-down.

Start-up problems differ little from those associated with the processing plant except where secondary biological treatment is involved. Start-up of secondary biological systems is made much easier if the biological solids have been retained in the secondary system, under water cover, from the previous operating season. In this case start-up of all secondary plant equipment at operating water levels should begin two or three days before wastewater treatment begins. Sludge recycles should begin with the early equipment start-up. In this way there will be a ready microbial culture available to provide a reasonable level of secondary treatment to the food processing wastewaters from the very first day of the annual startup.

At seasons-end biological treatment plants need to be shutdown in a manner that will retain the microbial mass for the subsequent start-up. This will involve, for all aerobic systems, gradual reduction in oxygen input over approximately one month's time, or until the microbial mass has been sufficiently "aerobically digested" to permit storage in aeration tanks, other secondary treatment reactors, and secondary clarifiers. Low level or periodic aeration may be necessary to keep the system completely odor free.

Changes in wastewater quantity or character during an operating season can be best accommodated when advance warning of the change is available. For instance, if operating an activated sludge plant on a high strength but low flow wastewater, a basic change may be required before receiving a low strength, high flow wastewater. That is, it may be necessary to reduce the MLSS concentration to avoid overloading the secondary clarifier at the higher flow (see Section 4.2343). Depending upon solids wasting, conditioning, and disposal capacity, this may take from one day to a week or more. Increasing microbial solids inventory to meet increased mass BOD loadings also takes several days. Again, the key to effectively adjusting treatment plant operations to meet changing wastewater quantity or character is advance warning of the nature, extent, and timing of probable change.

SECTION 5

SOLID WASTE UTILIZATION AND DISPOSAL

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SECTION 5
SOLID WASTE UTILIZATION AND DISPOSAL

LIST OF FIGURES

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5.0

INTRODUCTION

The term "residuals" is preferred when describing materials that remain after the processing of primary products. Some residuals have utility in by-products and other uses. The term "wastes" can then be reserved for those residuals which have no further current utility and must be disposed.

The food processing industry generates over 10 million tons of residuals annually. The sources, quantities, and types of disposal methods have been discussed (Section 1.23), as well as recommended in-plant handling procedures (Section 2.3). The purpose of this section is to provide additional information and a few details regarding proven methods of utilization and disposal. Although most of the information is general in nature, it is hoped that sufficient details are provided to enable a processor to evaluate various alternatives for their potential applicability to his situation. Sources for additional details are included, where possible, so that the processor can obtain further information with which to determine the practicality of potentially applicable alternatives.

5.1

UTILIZATION OF SOLID RESIDUALS

The conversion of residuals to useful by-products depends on numerous factors, such as the suitability of the residual materials, the feasibility (technological and economic) of further processing, proximity of the source to the user, and availability of similar materials, to name a few. The factors vary among and between regions and commodities, resulting in variability of by-product outlets as listed in Table 5.01. In the table "feed" is primarily animal feed; "fertilizer" includes soil conditioner; "non-food" means the recovery of metal, cardboard, paper, and other non-food wastes; "other" includes a few miscellaneous uses and unclassified by-products; and "none" includes by-product uses that are unknown.

In the study more than a third of the plants did not report use of residuals in by-products and just over half reported use as feed. However, by-product conversion did not imply a financial return. On the contrary, many plants incurred a net cost to convert residuals to by-products while others broke even. In these cases the decision to use residuals may have been based upon a lower net cost compared to disposal, or upon aesthetic or ecological considerations – utilization, where feasible, is preferred to disposal simply for conservation of resources.

5.11 Fiber (Non-food) Materials

Of the variety of non-food residuals generated by the industry, paper stock (cardboard or fiber) is most readily recycled. A variety of new paper products are being manufactured from recycled paper, thereby decreasing the demand for trees and thus preserving existing forests The feasibility of recycling fiber materials is highly dependent upon the proximity of the food processing facility to a recycling plant or center. These are generally located close to large metropolitan areas where the supply of waste paper and the demand for remanufactured goods are high. Locations of waste paper buyers may be obtained from the American Paper Institute, 260 Madison Avenue, New York, NY 10016.

Waste paper, especially cardboard cartons, is bulky and difficult to transport when loosely gathered. To facilitate handling baling machines (Figure 5.01) are recommended – most recycling companies require waste paper to be baled. Suitable paper balers are available in a range of sizes from a number of manufacturers; several are listed in Table 5.02. Baling will also minimize storage space requirements, ease housekeeping, and increase returns by reducing shipment costs.

5.12 Using Fruit and Vegetable Residuals for Animal Food

Vegetable residuals as well as some from fruits, are largely used as animal food (Figure 5.02). Residuals so used are either fed directly, converted to silage and stored for later use, or mixed with other feed materials in formulated blends. The feasibility of feeding and the method of feeding depend upon the nature of the residuals and the demand for feedstuff.

5.121 DIRECT FEEDING

Fruit and vegetable residuals can create environmental problems of public health concern if allowed to stand for prolonged periods. They attract insects and rodents, providing breeding sites for the former, and they readily putrefy, giving rise to offensive odors. Thus, a few precautions should be exercised when direct feeding is practiced.

The quantity of residuals fed to animals should not exceed the amount that can be consumed within a relatively short period as determined by the number of animals and their preference for the residuals. The residuals should not be stockpiled

TABLE 5.01
BY-PRODUCT OUTLETS[1]
(percentage of plants)

By-product use	New Eng.	Mid Atl.	South Atl.	North Cent.	South Cent.	Mount-ain	North West	Alas-ka	South West	Total
Feed	21	26	50	55	42	73	80	9	54	52
Charcoal	0	0	0	1	0	0	0	0	16	4
Alcohol	0	0	0	0	0	0	4	0	9	3
Vinegar	0	5	0	4	0	0	3	0	0	2
Oil	0	0	3	0	0	0	1	9	10	3
Fertilizer	29	0	0	2	0	0	3	0	3	3
Non-food	0	5	3	8	11	0	4	0	14	7
Other	7	7	11	2	16	0	8	18	7	7
None	43	63	39	38	47	27	14	77	26	36

	Fruit	Tomato	Vege-table	Sea-food	Special-ty	Can Only	Can & Freeze	Freeze Only	Any Dehdr.
Feed	51	29	64	23	43	46	44	73	65
Charcoal	10	9	2	0	2	6	2	0	0
Alcohol	8	4	3	0	1	3	2	0	6
Vinegar	5	1	2	0	1	2	0	2	0
Oil	7	3	1	8	0	3	4	1	0
Fertilizer	1	0	1	9	3	2	5	2	0
Non-food	8	9	5	0	17	8	4	6	0
Other	7	4	3	17	13	5	2	9	6
None	27	54	22	57	40	38	42	19	29

The columns may add to more than 100% because some plants had two or more by-product outlets.

1. Katsuyama, A. M., N. A. Olson, R. L. Quirk, and W. A. Mercer. Solid Waste Management in the Food Processing Industry (PB-219 019). U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA. 1973.

on the ground – leachate (seeped liquid) may later cause odors and other environmental problems. Spreading the residuals over the ground is also undesirable since the animals will tend to trample much of the materials into the soil. The preferred method of offering the residuals to animals is in a feeding trough, thereby enabling closer control of quantities simply by observation and avoiding the environmental problems associated with unconsumed materials. In all cases good feeding practices should be followed.

The slurry of potato peel removed with dry scrubbers is almost entirely fed to livestock. Direct feeding is precluded by the high alkalinity caused by sodium hydroxide carryover from the caustic applicators. The slurry from the scrubbers is pumped to separate holding tanks or hoppers and transported to the feedlots in tank trucks. The slurry is discharged into concrete pits and allowed to remain for several days. During the holding period fermentation occurs and the organic acids generated during the process are sufficient to quickly neutralize the residual sodium hydroxide. After the pH is neutralized, the slurry is pumped from the pits, mixed with other materials (such as cull potatoes and trimmings), and fed directly to the animals. Self-neutralization will occur when the slurry from "dry" chemical peeling of other vegetables and fruits is held in a similar manner. Such handling may render these otherwise waste materials useful for feeding or facilitate their disposal without the need for chemical addition.

5.122 SILAGE

The practice of ensiling solid residuals from corn, pea, lima, and green bean processing is widespread. By so preserving these materials, the availability of animal feed is extended well beyond the harvesting season. The method of ensiling is no longer limited to silos; pits, walled windrows, and large open stacks are commonly used (Figure 5.03).

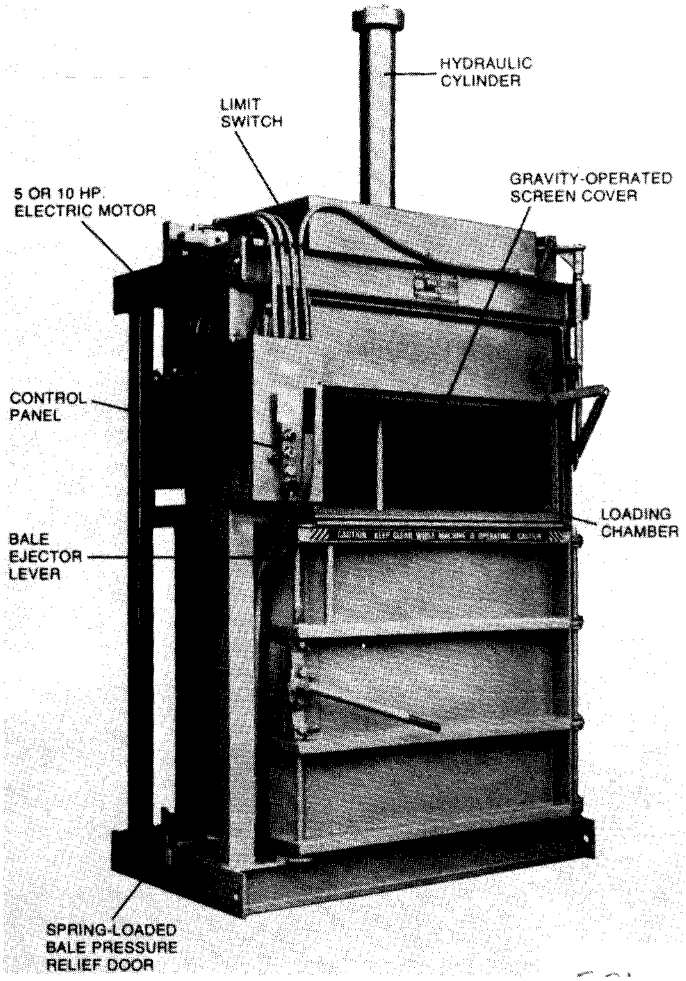

Figure 5.01. Waste paper baler.

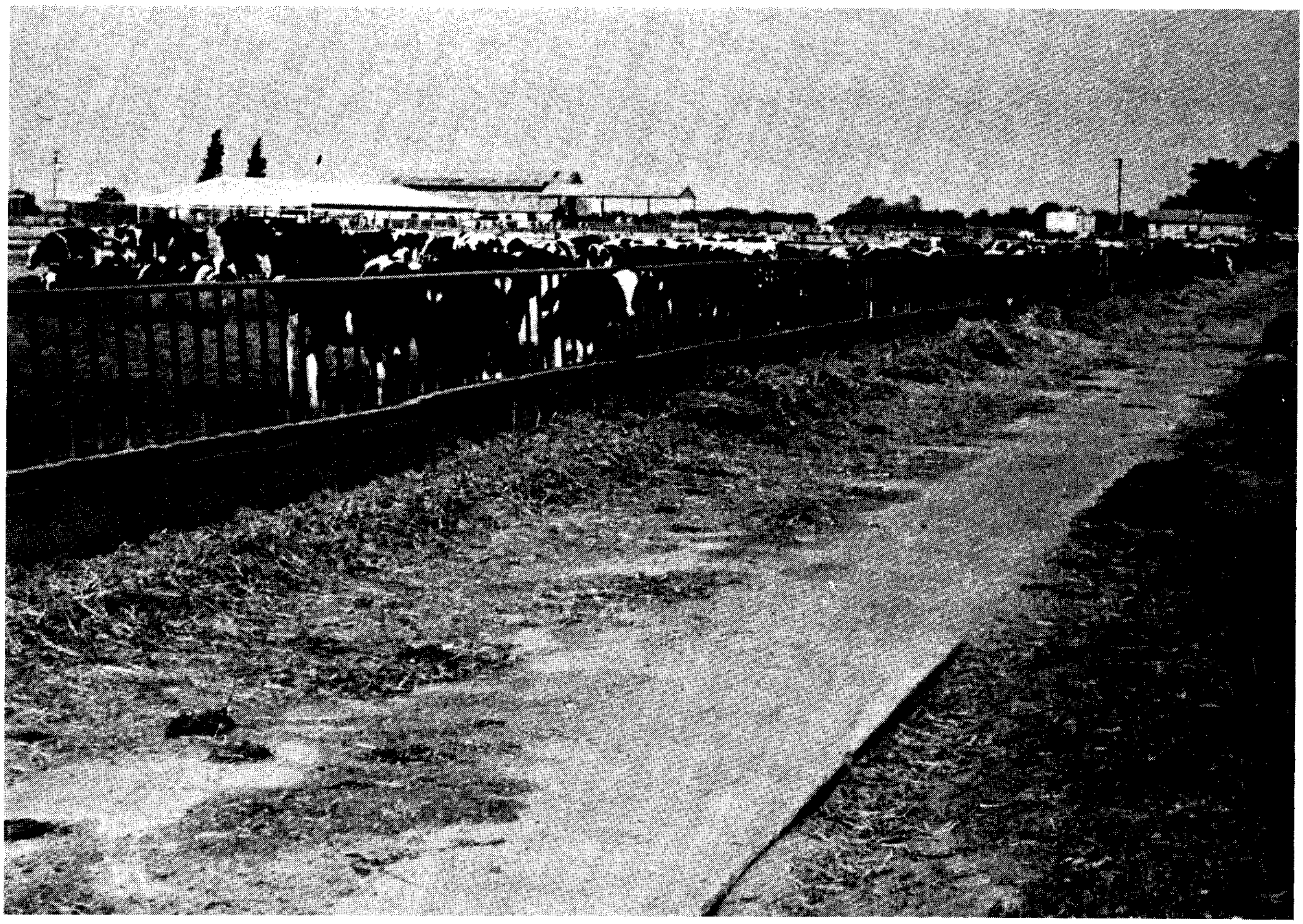

Figure 5.02. A cattle feeding operation.

Solid residuals intended for storage are usually chopped to aid compressibility and reduce space requirements. Some freshly chopped materials ("green chop") are frequently fed directly to animals and the excess is hauled to the storage site, spread in layers, and compacted. Fermentation which naturally occurs is responsible for preservation. Details of procedures may be obtained from the nearest University Agricultural Extension office or the local Farm Advisor.

The primary disadvantage of silage is the odor associated with fermenting residuals. Thus, the location of the mass must be carefully selected. The second major problem is created by the large volumes of extremely strong liquid that will seep from ensiled matter. To minimize problems (odor, insect attraction, water pollution) associated with this liquid, the ensilage should be placed on a relatively impervious base. The base should be graded such that the flow of seeped liquid can be directed to a collection point. Provisions should be made to treat the collected fluid in a manner that will prevent environmental problems.

5.123 OTHER ANIMAL FOOD USES

The industrial practice for processing some commodities includes utilization of residuals for animal food. In addition to those mentioned above, citrus and pineapple residuals are almost entirely fed to animals, in many cases following partial dehydration. Furthermore, juices from oranges and pineapples are commonly concentrated with "waste heat evaporators" into molasses which is added to the feed to increase its palatability. Information on waste heat evaporators may be obtained from the Gulf Machinery Corp.[1]

Tomato residuals are somewhat unique because of the oil and protein content in the seeds. In addition to the use of tomato pomace as livestock feed, smaller quantities are dehydrated for use in pet food formulae and as a food for fur-bearing animals (chinchilla, mink). The oils are said to impart a desirable sheen to the coats of the fur bearers, thus enhancing their market value. Unfortunately, the demand for tomato pomace for this use is low while the costs for dehydration continue to escalate.

5.13 Charcoal Briquets from Peach Pits

The processing of cling peaches, a major California fruit crop, results in the annual generation of thousands of tons of peach pits. These pits are said to be close-grained and the hardest of wood fibers available in commercial quantities. These physical features, which are preferred for making char-

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[1] Gulf Machinery Corporation, 3149 State Road 590, Clearwater, Florida 33518. Phone: 813/726-1127.

Figure 5.03. An open silage stack.

coal, led to the utilization of peach pits as the basic raw material for producing charcoal briquets.[1]

Peach pits are segregated at a number of close-by canneries. The pits are cleaned of most adhering peach flesh with rotating abraders and delivered to the charcoal manufacturer at an average of 500 tons per day during the peach season. Dump trucks unload the peach pits into two 20-ton receiving hoppers. Fruit juices and free water drain through the mesh bottom of these hoppers and are pumped into a large tank for separate treatment and disposal. The pits are then moved by belt, screw conveyor, blower, and bulldozer to a large, open storage area where they are allowed to dry for a full year (Figure 5.04).

By stockpiling the wet pits high temperatures are created during decomposition of residual organic matter, thereby preventing the breeding of insects. To minimize insect congregation and to eliminate odor, the surface of the pile is sprayed daily with insecticide and bi-weekly with a deodorant. This treatment is continued for 30 days after the last load of the season has been received. It has been found to be unnecessary to continue spraying or deodorizing thereafter.

The dried pits are moved with front-loaders and passed over three screens to remove dirt and other foreign matter. Ferrous metals are removed by magnets. The pits are then passed through two rotary pre-dryers where they are heated to approximately 250°F to remove as much moisture as possible. They are then screened a fourth time prior to entering the char kiln. Repeated screenings are necessary to remove adhering dirt which, if allowed to enter the kiln, will be converted to glass at the 1600°F temperature and significantly reduce the efficiency of the kiln and increase its maintenance costs.

The pits entering the kiln are rapidly heated to 800°F (Figure 5.05). Gases emitted by the pits increase the temperature to 1600°F, thus requiring only a minimum of natural gas to fuel the oven. A suction fan is used to pull hot air through the pre-dryers and to inject the air into the stack to burn the volatiles evolved during the charring process. Temperatures in the bricklined chimney exceed 2000°F, resulting

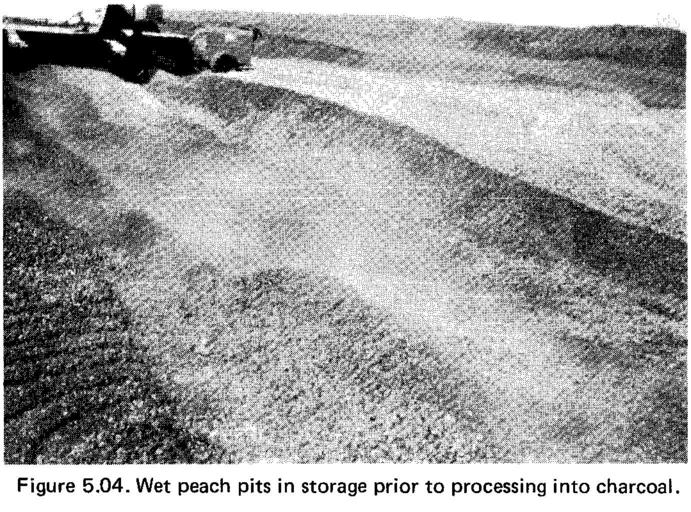

Figure 5.04. Wet peach pits in storage prior to processing into charcoal.

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[1] Collier Super Charcoal Briquets^{TM} manufactured by C. B. Hobbs Corp., P.O. Box 607, Santa Clara, CA.

TABLE 5.02

MANUFACTURERS OF PAPER BALERS

Allplas Div, Wire Sales Inc.
4630 West 54th St.
Chicago, IL 60632
312/767-2500

American Environmental Prod.
RR3 Box 550-C
Sewell, NJ 08080
609/589-3000

Baler Equipment Co.
5201 SW Westgate Dr., 102
Portland, OR 97221
503/292-0769

Consolidated Baling Machine
156 Sixth St., Rm 19168
Brooklyn, NY 11215
212/625-0928

K. L. Cook & Assoc., Inc.
Waste Div.
Sugar Creek, OH 44681
216/852-2411

Econo-Therm Energy Systems Co.
11321 K-Tel Dr.
Minnetonka, MN 55343
612/938-3100

Fox Manufacturing Co.
3530 W. Peterson Ave.
Chicago, IL 60659
312/463-4947

Logemann Bros. Co.
3150 West Burleigh St.
Milwaukee, WI 53210
414/445-2700

Lummus Industries, Inc.
Box 1260
Columbus, GA 31902
404/322-4511

Maren Engineering Corp.
Box 278
South Holland, IL 60473
312/333-6250

McLanahan Corp.
200 Wall St.
Hollidaysburg, PA 16648
814/695-9807

National Compactor & Tech. Sys.
Box 6922
Jacksonville, FL 32205
904/358-3812

Ohio Blow Pipe Co.
424 East 131st St.
Cleveland, OH 44108
216/681-7379

Peabody E-Z Pack
P.O. Box 607
Galion, OH 44833
419/468-2120

Piqua Engineering, Consv. Div.
Box 605
Piqua, OH 45356
513/773-2464

Rescor, Inc.
125 Gaither Dr.
Mt. Laurel, NJ 08054
609/234-2770

Strycopak Div., Stryco Mfg. Co.
336 Seventh St.
San Francisco, CA 94103
415/861-2140

Vira Corp.
33 E. Magnolia
Stockton, CA 95202
209/465-0245

Also check "Yellow Pages" under *Baling Equipment & Supplies.*

in no emission of smoke or dust particles into the atmosphere. The char plant produces 35 tons of charcoal in a 24-hour period, using 120 to 140 tons of dried peach pits. The charcoal is aged for a minimum of two weeks prior to processing into briquets.

The aged charcoal is ground in a hammermill and the ground char is mixed with edible cornstarch and water at 160°F to make the material cohesive. The mixture is pressed into pillow-shaped briquets (Figure 5.06) which are then slowly conveyed through a 300°F drying oven for two and one half hours. The moisture in the briquets is reduced from 30% down to 5%. The dried briquets are stored in two 60-ton hoppers which feed automatic filling machines producing 5, 10, 20, and 40-pound bags.

5.14 Olive Pits as Fuel[1]

The olive processing season occurs for seven or eight months of each year. During this period over 10,000 tons of olive pits are generated. Some of the pits are used for olive oil production, as a roadbed material for driveways, and for several other minor and sundry purposes. However, their utility has been extremely limited. The disposal of these pits is becoming increasingly problematic because of adhering olive flesh.

At one olive plant producing about 30 tons of pits daily, the problem of disposal was especially acute. Numerous attempts at by-product uses failed for economic reasons. Tests on wet pits, however, revealed an energy value of 4000 BTU per wet pound, despite the high (almost 50%) moisture content. An incinerator[2] (Figure 5.07), capable of burning wood chips containing up to 60% moisture, was installed to burn the pits for steam generation.

The incinerator consists of a tank lined with a high-strength refractory material and high temperature insulation blocks. A layer of refractory sand is placed in the bottom. A natural gas flame is used to initially heat the sand, while air from a large blower is used to fluidize the bed and to create a vortex of hot gases (1800°F) within the unit. Once up to operating temperature, the system is self-sustaining and requires no more natural gas.

Olive pits are screened to remove free liquid and metered into the top of the incinerator. As the pits fall and spin in the hot air, they are dried and heated. Complete combustion of the pits occurs in the fluidized bed. The hot gases are vented through the duct and through the fire tubes of a conventional

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[1] Based on information from J. R. Webster, Research Director, Lindsay Olive Growers, P.O. Box 278, Lindsay, CA 93247.

[2] Energy Products of Idaho, P.O. Box 153, Coeur d'Alene, ID 83814.

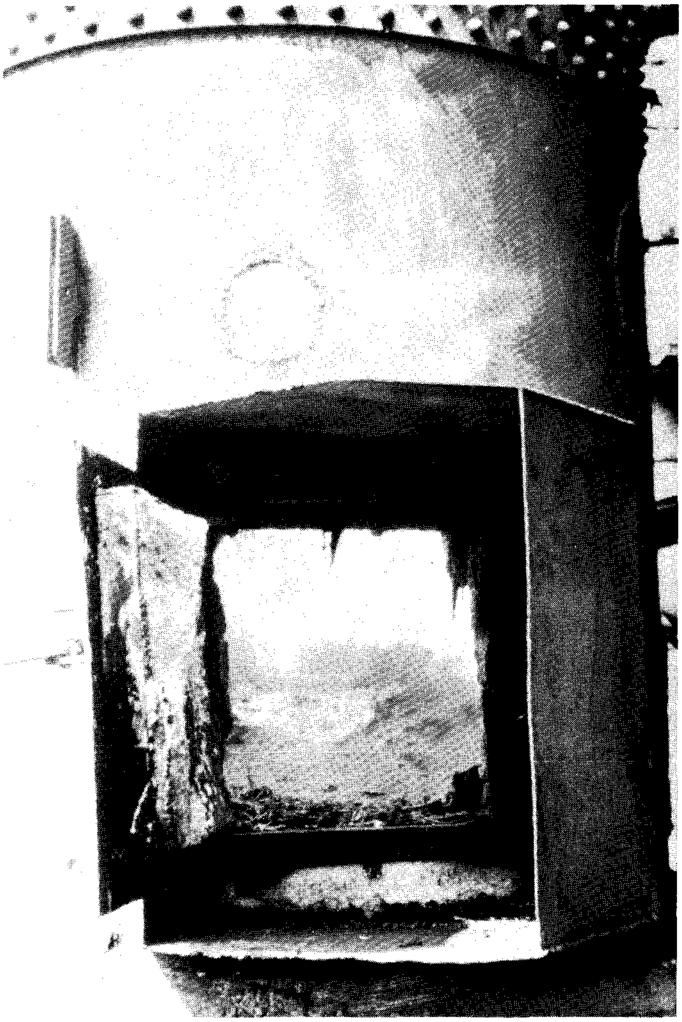

Figure 5.05. Kiln at 1600° F. to char the dried pits.

Figure 5.06. Dried briquets ready for packaging.

boiler. Ash and other particulates carried with the effluent gases are removed with a series of cyclone collectors. Automatic controls regulate the rate at which the pits are metered into the system, based on the temperature of the combustion gases and the steam pressure within the boiler.

By feeding the pits directly from the pitter to the incinerator, the development of environmental problems associated with prolonged storage is prevented. In utilizing the total daily output of pits, the processor has been able to generate one-third of the steam required at the facility, thereby reducing natural gas consumption by a proportional amount. This system is available in a wide range of sizes and is capable of burning pits from all stone fruits.

5.15 By-products from Seafoods

The feasibility of utilizing residuals from seafood processing is highly variable. The primary determinant is economics, which, in turn, is influenced by numerous factors. Foremost among these, aside from the obvious one of demand for potential by-products, are the varying raw materials represented by the contrasting fisheries (i.e., fish vs. shellfish, as well as species variability), the quantities of generated residuals, the location of the processing facility, and competition of the by-products with other products on the open market. Nevertheless, residuals from seafoods are successfully utilized, although such uses may be justified only in limited situations. Some of the prevalent by-products are discussed in this section with brief consideration of the above factors.

The location of the processing facility is worthy of special consideration – specifically, plants located in remote regions, such as Alaska, compared to those located in populated areas. The conversion of residuals to by-products by isolated plants is generally neither practical nor necessary. By-products are usually impractical because these plants typically operate only during a short period each year and transportation costs impose severe competitive disadvantages. By-products are often unnecessary because plant isolation offers a unique alternative. The residuals, whether fish viscera or crab/shrimp shells, are from organisms harvested from the sea. The return of these materials to their origin, where they may re-enter the food chain, is recycling in a classic form and waste utilization in a natural manner. This alternative, practiced with minimal precautions to prevent long-term environmental problems, will also result in the savings of energy required by those processes discussed below.

5.151 UTILIZATION OF FISH RESIDUALS

The following by-products are commonly manufactured from fish processing residuals. However, they are also the primary products into which some species of fish are processed. For example, herring, once primarily used for canned sardines, is now largely used for whole fish meal and fish oil. The equipment required to produce the products is expensive, expansive, and energy intensive. Thus, a relatively continuous supply of residuals in sufficient quantity is required for economic justification.

5.1511 Fish Meal and Oil

There are several processes by which fish meal and oil may be manufactured from whole fish or food fish processing residuals. The most widely-used method is called "wet processing," a continuous operation capable of handling large quantities of oily fish. The wet process is described below. When handling smaller quantities of fish with low oil content, such as haddock, flounder, pollock, or hake, the batch operation of the "dry process" is more practical. Descriptions of the dry process, as well as details of the wet and other processes, may be found in the references listed at the end of the section.

The wet process is schematically diagrammed in Figure 5.08. The raw materials are initially cooked in a large continuous cooker, either with direct steam injection or steam-jacketed thermal screws. During this step the proteins are denatured and coagulated and the cell walls are ruptured to release oil and water. The hot, cooked mass is compressed with screw presses, yielding a press liquor of oil and water, which is usually further processed to recover fish oil, and a press cake with about 50 percent moisture. The pressed solids are milled to facilitate drying to 8-10% moisture in forced-draft, gas-fired rotating dryers. The dried material is again milled, conveyed by blower to facilitate cooling, and stored in bulk or bagged.

The hot press liquor is generally screened to remove coarse solids and centrifuged to remove fine particulates. The solids are returned to the meal flow. The relatively-clear liquid is reheated, if necessary, and passed through an oil centrifuge.

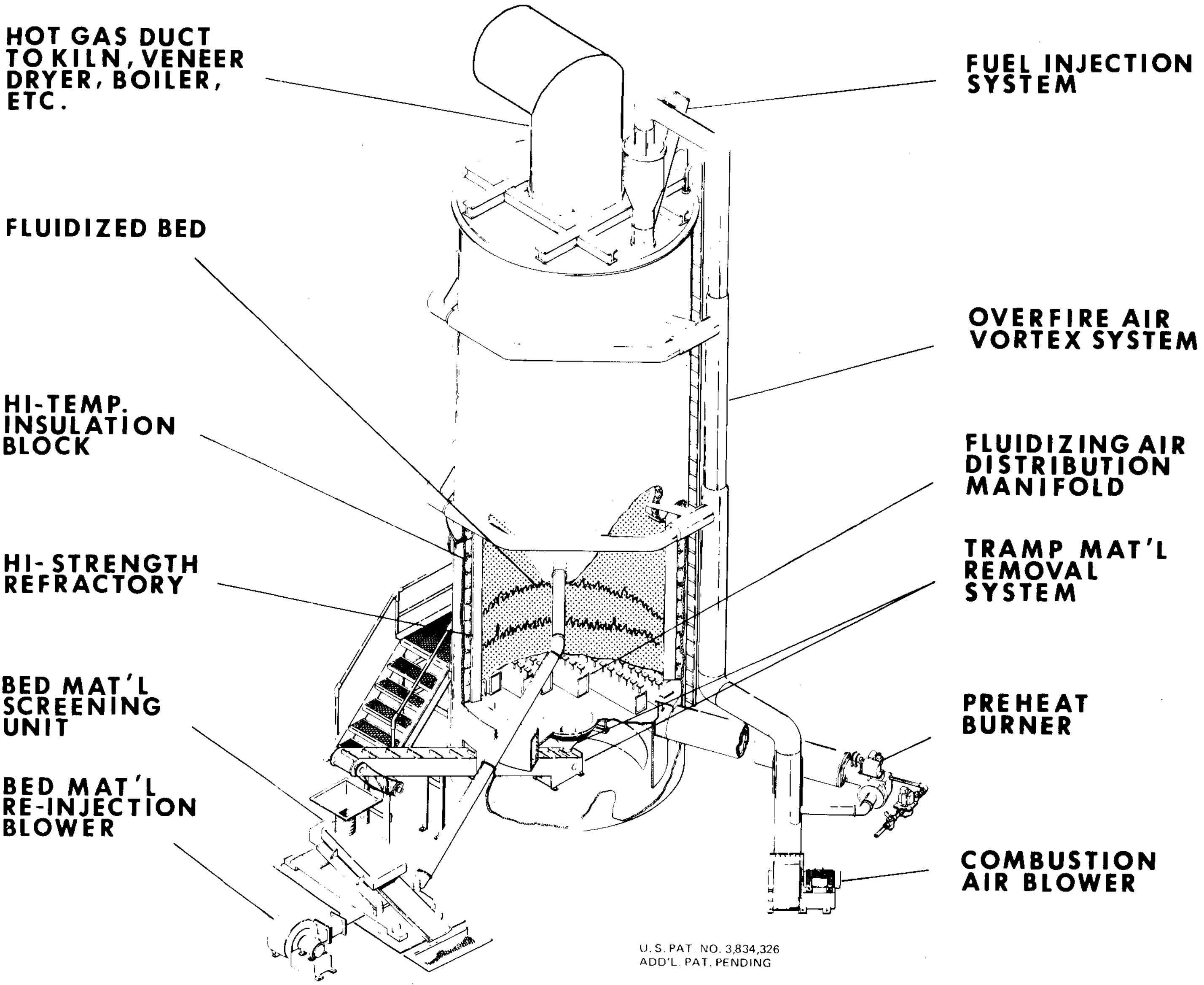

Figure 5.07. Schematic diagram of the Fluid Flame^{R}incinerator.

The clear oil is "polished" in a second centrifuge and stored for shipment. The undesirable liquid, popularly called "stickwater," is used to manufacture concentrated fish solubles.

The wet process requires relatively large amounts of oily fish, such as tuna, herring, anchovy and mackerel, to be economic and efficient. Small quantities or irregular supplies will result in a low-grade meal that will virtually be unmarketable. Thus, the manufacturing of fish meal from residuals is limited to large processing facilities or to plants simultaneously producing whole fish meal. Another problem associated with fish meal production is the odors which emanate from dryers. Gas scrubbers or incinerators should be considered, especially when the plant is located in developed areas, to avoid air pollution.

Fish meal is largely used in formulation of feeds for pigs and poultry and to a lesser extent for ruminants. It serves as an animal protein supplement and as a source of vitamins, minerals, and unknown growth factors. Its value, however, is determined by consistency in quality, an attribute which requires extreme care of raw product quality and operating conditions. Fish oil is used primarily as a carrier in paint formulations. Oils from the livers of some fish species are very high in Vitamins A and D and are used specifically for recovery of these components.

References

Brody, J. *Fishery By-Products Technology.* The AVI Publ. Co., Inc., Westport, CT. 1965.

Clandinin, D. R. "The Effects of Methods of Processing on Value of Herring Meal." *Poultry Science, 28:*128-133. 1949.

Lee, C. F. "Processing Fish Meal and Oil," in Stansby, M. E. (ed.). *Industrial Fishery Technology.* Reinhold Publ. Corp., New York. 1963.

Meade, T. L. "A New Development in Fish Meal Processing," *Feedstuffs, 28*(20):14, 16, 121-122. 1956.

Sanford, F. B. and C. F. Lee. "U.S. Fish Reduction Industry," *Technical Leaflet No. 14.* Washington Bureau of Commercial Fisheries. 1960.

Sparre, T. "Small Scale Manufacture of Fish Meal," *FAO Fisheries Bull. No. 6* (1-2):1-17. 1953.

Sparre, T. "Fish Meal: Manufacture, Properties, and Utilization," in Borgstrom, G. (ed.). *Fish as Food: Vol. III, Processing: Part 1.* Academic Press, New York. 1965.

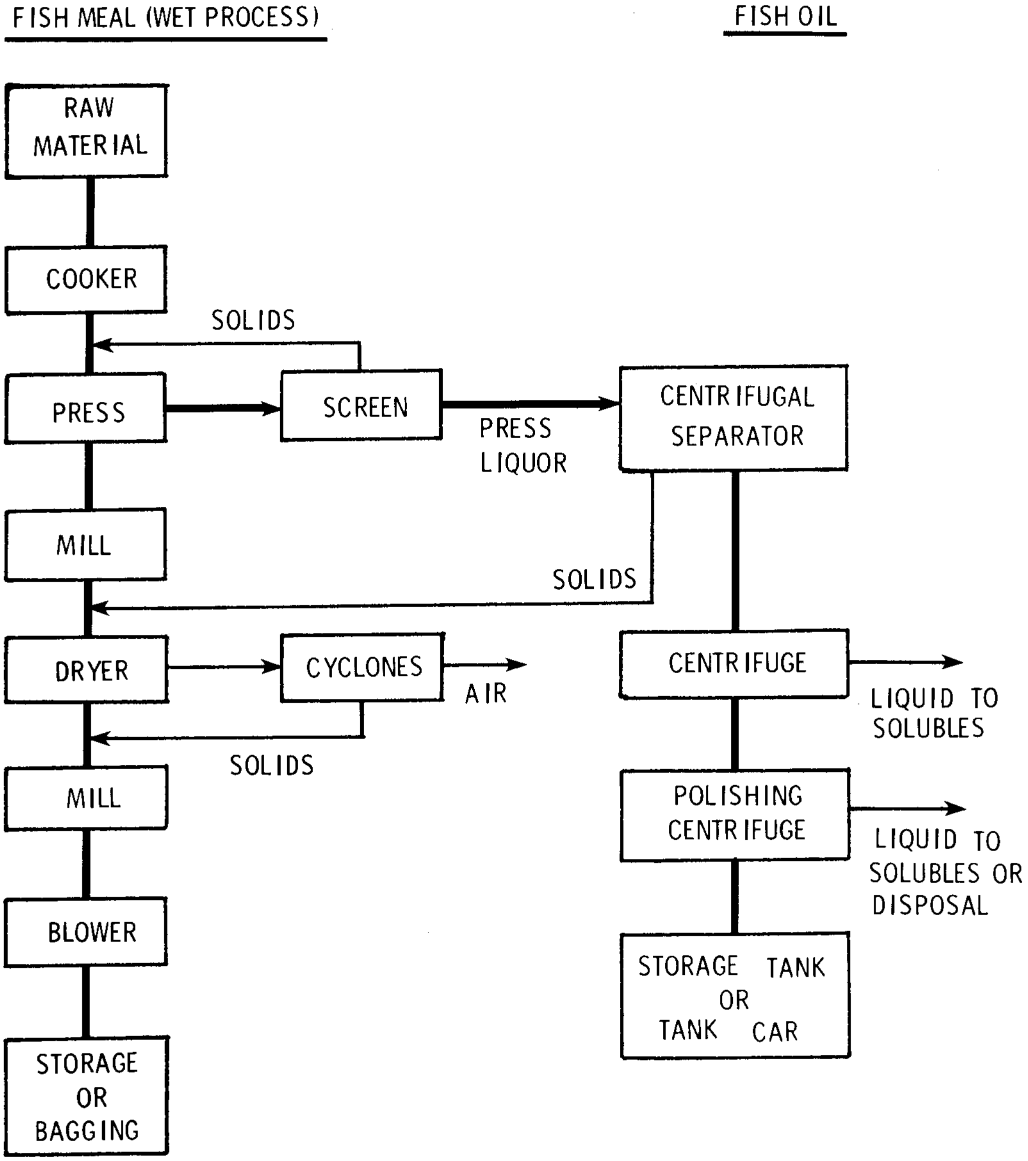

Figure 5.08. Flow diagram of major steps in the production of fish meal and fish oil.

5.1512 Fish Solubles

"Stickwater," the viscous press liquor from fish meal operations, is the primary material from which concentrated fish solubles are manufactured (Figure 5.09). The juices generated during the cooking of some fish, such as tuna, are usually mixed with stickwater prior to processing. The formerly-wasted liquid effluents are initially held in a storage tank and heated for several hours. During this period naturally-occuring or added enzymes and thermophilic bacteria breakdown the protein, reducing the viscosity of the finished product.

In the conventional process the liquid is concentrated, most commonly in vertical triple-effect evaporators, to the desired solids level (35-50%) and acidified with sulfuric acid to pH 4.0-4.5 for preservation. In the Lassen process the raw, unheated stickwater is initially acidified to coagulate proteins, to precipitate some of the insoluble solids, and to free suspended oil. The acidified mixture is then centrifuged to remove solids, which are returned to the meal production process. The liquid is reheated, centrifuged a second time to separate free oil, and then concentrated to the desired level, usually about 50 percent. The concentrated fish solubles are held in storage tanks for shipment.

The use of triple-effect evaporators generally prevents the development of air pollutants. However, these expensive units require the production of a relatively large quantity of solubles for economic justification. Smaller volumes may be processed in batches with steam-jacketed kettles, but air pollution prevention measures will normally be required.

Concentrated fish solubles were once widely used as a feed supplement because of their high vitamin content. However, milk products have largely replaced fish solubles as a source of Vitamin B_2 in feeds. Concentrated fish solubles are now sold primarily as a fertilizer, especially to the home gardener.

References

Brody, J. *Fishery By-Product Technology.* The AVI Publishing Co., Inc., Westport, CT. 1965.

Lassen, S. "Process for Treating Fish Press Liquor," U.S. Patent Number 2,372,677. April 3, 1945.

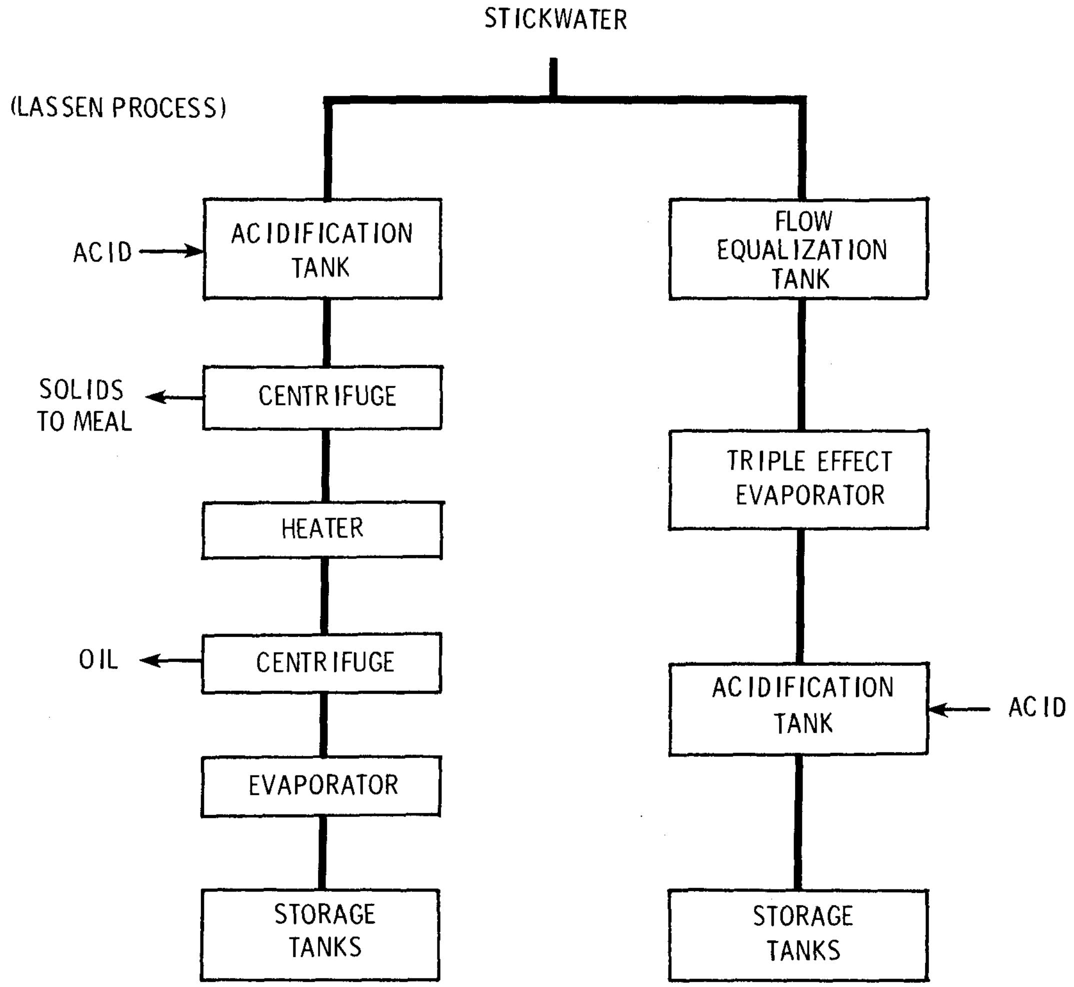

Figure 5.09. Flow diagram of condensed fish solubles production.

Lassen, S., E. K. Bacon, and H. J. Dunn. "Fish Reduction Process," *Ind. Eng. Chem., 43*:2082-2087. 1951.

Lassen, S. "Fish Solubles," in G. Borgstrom (ed.). *Fish as Food: Vol. III, Processing: Part 1.* Academic Press, New York. 1965.

Lee, C. F. "Processing Fish Meal and Oil," in M. E. Stansby (ed.). *Industrial Fishery Technology.* Reinhold Publ. Corp., New York. 1963.

5.1513 Fish Protein Concentrate (FPC)

In light of wide-spread malnutrition among the world population, the utilization of fish meal for human food has been considered for some time. Since fish meal produced for animal food by conventional processes is unsuitable as food for human consumption, studies have been conducted to improve these processes. In all cases a stable high-quality protein end-product has been sought, generally one without strong fish taste or odor. Since deodorization and stability require defatting, the developed processes include solvent extraction. Information on several processes may be found in the references listed below.

Fish protein concentrate, also called fish flour, requires the use of fresh, whole fish to yield a high-quality protein. However, fresh fish offal can be used to produce a low-quality protein product. Fish protein concentrate can be beneficially used as a protein supplement in breads and cereals, especially among undernourished people. Its acceptability has been demonstrated when the material has been deodorized, although preference for non-extracted material has been expressed by African and Asian peoples. The manufacture of FPC requires expensive installations, particularly for extracted product, and the market for the material has not been well developed. Currently, FPC does not appear to be a practical method for utilizing fish residuals.

References

Barlow, S. M., and F. W. Burton. "The Role of Fish Meal in Alleviation of Protein Shortage in Human Nutrition," in R. Kreuzer (ed.). *Fishery Products.* Fishing News Books Ltd., Surrey, England. 1974.

Brody, J. *Fishery By-Products Technology.* The AVI Publishing Co., Inc., Westport, CT. 1965.

Dreosti, G. M. "The Future of Powdered Fish Products," in R. Kreuzer (ed.). *Fishery Products.* Fishing News Books Ltd., Surrey, England. 1974.

Levin, E. "Fish Flour and Fish Meal by Azeotropic Solvent Processing," *Food Technol., 13*(2):132-135. 1959.

Sparre, T. "Fish Meal: Manufacture, Properties, and Utilization," in G. Borgstrom (ed.). *Fish as Food: Vol. III, Processing: Part 1.* Academic Press, New York. 1965.

U.S. Dept. of the Interior, Fish and Wildlife Service.
Fish Protein Concentrate, Report No. 1: Past and Present Developments. 1962.
Fish Protein Concentrate, Report No. 2: The Resource. 1962.
Fish Protein Concentrate, Report No. 3: Hunger, Man and the Sea. 1962.

5.152 UTILIZATION OF SHELLFISH RESIDUALS

In the processing of shellfish a large portion of the weight and volume of received raw products becomes solid residuals.

Hence, solid waste disposal is of major concern for many shellfish processors. Conversion of residuals to salable by-products will, of course, reduce the quantity which must be disposed of. The more common by-products are discussed below. However, the economic feasibility will vary between plants among each industry segment and will largely be influenced by the proximity of each plant to the by-product market, as well as the competition within those markets by alternative materials that may be readily and cheaply available. Although the following by-products are not widely manufactured, several commercial operations do exist.

5.1521 Crab and Shrimp Meal

Crab processing residuals consist largely of shells and viscera. Since regulations prohibit the processing of dead crabs, the residuals will also contain a small quantity of whole crabs. Shrimp processing residuals consist almost entirely of shells and heads removed at the plant, combined with small quantities of trash fish caught and delivered with the shrimp. These materials are either handled separately in containers or removed from wastewater by screens.

Crab and shrimp residuals are high in protein and calcium. The main utility of these materials is in feeds for egg-laying hens and growing chicks, both of which require a high calcium diet. To reduce the calcium concentration in livestock feed, the residuals may be mixed with other packing plant residuals, such as cattle, fin-fish, and poultry plant wastes, or blended with other feedstuffs in formulated rations. Shrimp meal is also vacuum dried and used in the formulation of commercial trout food. The red pigment in the shrimp is said to impart a pink coloration to the flesh of the fish and a flavor more closely associated to that of wild trout. Shrimp meal has also been used as mink food. Both crab and shrimp meal have also been utilized as fertilizer.

Crab and shrimp residuals are usually collected from individual plants and processed into meal at a central facility. The typical process for meal production includes drying the residuals in heated rotary drums and grinding the dried material in hammermills. The meal may be bagged for small lot shipment or shipped in bulk.

References

Lee, C. F., and F. B. Sanford. "Crab Industry of Chesapeake Bay and the South – An Industry in Transition." *Commercial Fisheries Review, 26*(12):1-12. 1964.

Lubitz, J. A., C. R. Fellers, and R. T. Parkhurst. "Crab Meal in Poultry Rations. Nutritive Properties." *Poultry Science, 22*(4):307-313. 1943.

Mendenhall, V. "Utilization and Disposal of Crab and Shrimp Wastes." *Marine Advisory Bulletin No. 2.* Univ. of Alaska, Fairbanks, AK. March, 1971.

Novak, A. F. "Sea Grant Program – Marine Food Science." *Summary of the First Meeting of Sea Grant Food Science and Technology.* Sea Grant Marine Advisory Program, Oregon State Univ., Corvallis, OR. 1970.

Tressler, D. K., and J. McW. Lemon. *Marine Products of Commerce.* Reinhold Publ. Corp., New York. 1951.

5.1522 Chitin and Chitosan

The exoskeleton of crustacea is composed of chitin, protein, and minerals (largely calcium carbonate). Chitin, the primary component, is a polysaccharide similar in structure to cellulose. Like cellulose, chitin and its derivatives possess some abilities to form filaments and films and to absorb dyes. However, it is soluble only in concentrated mineral acids and is unstable when dissolved. Therefore, no important uses have been developed for chitin itself. On the other hand, a number of uses have been found for chitosan, a degradation product of chitin.

A process for "upgrading" shellfish residuals has been developed (Figure 5.10) whereby the principal components are chemically separated and recovered for individual marketing. The primary marketable endproduct is a high protein extract suitable for direct use as an animal feed or for refining to human food grade. Chitin is isolated as a chitin-calcium carbonate mixture which can be demineralized with hydrochloric acid to produce chitin and calcium chloride brines.

The chitin-calcium carbonate mixture may be used as a soil conditioner; the calcium carbonate is equivalent to agricultural lime while the chitin contains nitrogen (6-7 percent) which will be slowly metabolized by soil organisms. Alternatively, the mixture can be burned to produce heat and lime. These uses are possible where markets for demineralized chitin cannot be developed or where hydrochloric acid costs are prohibitive. The chitin-calcium carbonate mixture or the demineralized chitin may also be dried for shipment to a secondary processor. Chitin can also be converted directly without drying to soluble chitin derivatives.

Chitosan is produced by boiling chitin in a strong alkaline solution, generally 45-55 percent sodium hydroxide. Suggested uses for chitosan include moisture-proof films and coatings, sizing for paper and textiles, oil well drilling additives, thickening agents for foods, ink and cosmetics, ion exchange resins, and films and encapsulating agents for pharmaceuticals. The use of chitosan as a coagulant aid for water and wastewater treatment has been demonstrated. Although several of these uses have been shown to be feasible, current demands are being met with readily available, low cost materials, thereby discouraging widespread commercial production of this by-product.

References

Bough, W. A., D. R. Landes, J. Miller, C. T. Young, and T. R. McWhorter. "Utilization of Chitosan for Recovery of Coagulated By-Products from Food Processing Wastes and Treatment Systems." *Proceedings of the Sixth (1975) National Symposium on Food Processing Wastes* (EPA-600/2-76-224). U.S. Environmental Protection Agency, Cincinnati, OH. December 1976.

CRESA. *Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing.* (Water Pollution Control Series #12130 FJQ 06/71). U.S. Environmental Protection Agency, Washington, D.C. 1971.

Meinhold, T. F., and P. C. Thomas. "Chitosan–Useful Chemical from Shrimp Shells." *Chemical Processing, 21*:121-122. 1958.

Mendenhall, V. "Utilization and Disposal of Crab and Shrimp Wastes." *Marine Advisory Bulletin No. 2.* University of Alaska, Fairbanks, AK. March 1971.

Peniston, Q. P., E. L. Johnson, C. N. Turrill, and M. L. Hayes. "A New Process for Recovery of By-Products from Shellfish Waste." *Proceedings of the 24th Industrial Waste Conference.* Purdue Univ., Lafayette, IN. 1969.

5.1523 By-Products from Oyster and Clam Shells

Although oysters may be marketed unshucked (in the shell), most are sold as shucked meats. Clams are mostly processed by removing the shell and viscera. Oyster shells represent an estimated 75 percent of the total weight; clam shells are about 65 percent. These shells are composed main-

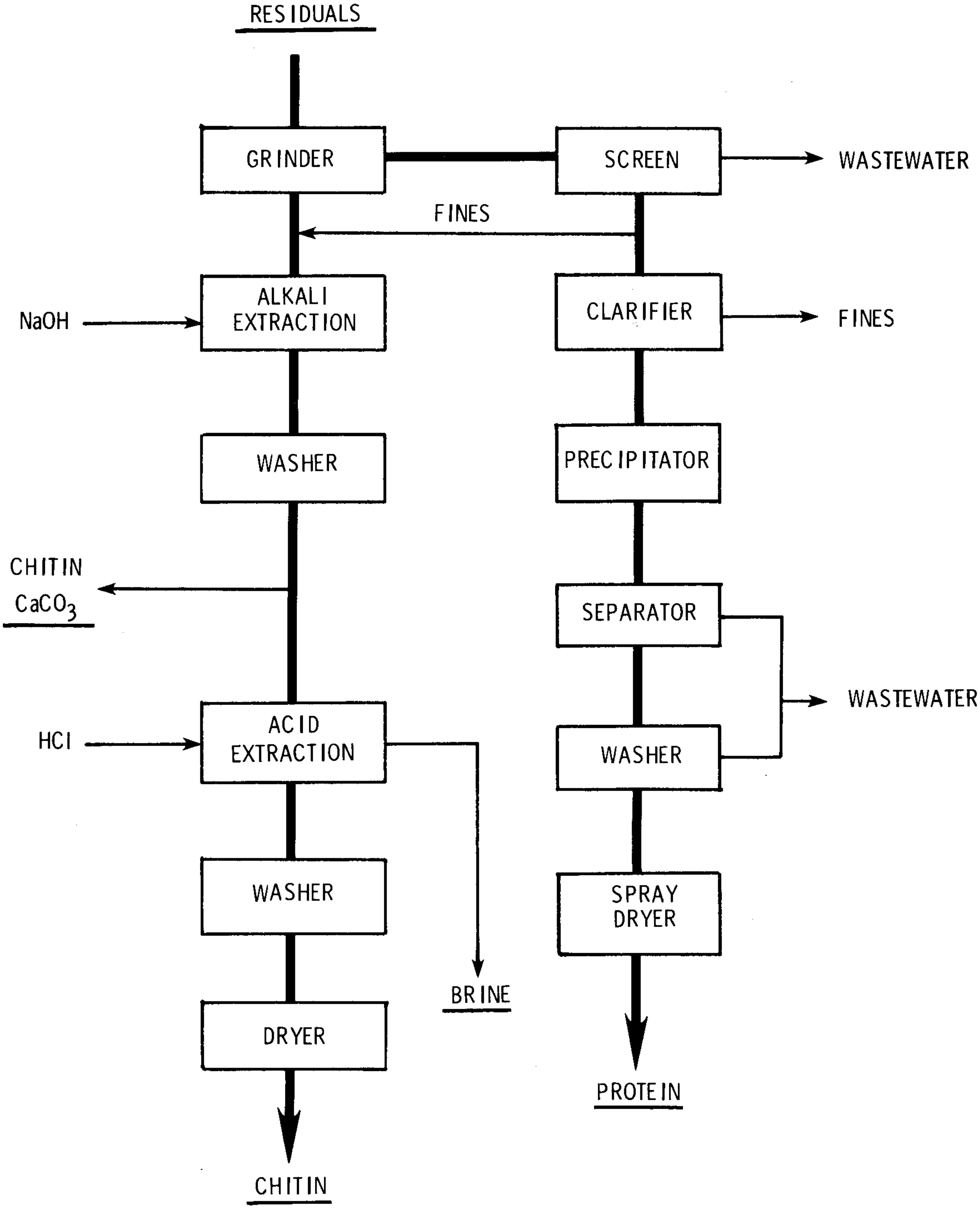

Figure 5.10. Shellfish waste treatmentprocess (from Peniston et al.).

ly of calcium carbonate, hence, the principal by-products are based on the utilization of this component.

Oyster shells are an important source of calcium in poultry feed formulations. The shells are dried, usually in rotary-drum dryers, and passed through a grinder, such as a hammermill, The particles are size separated with a series of vibrating screens and bagged according to mesh size or may be ground to a flour for use as a supplement in livestock feed. Clam shells, sometimes dredged from beds of dead shells in tidal flats, are prepared in a similar manner.

Lime, obtained burning the shells, has also been used to manufacture cement and for neutralizing acid wastes. In areas where shells are plentiful, such as in the Gulf States, they have been used as a road building material. Growers of cultured oysters frequently return large quantities of empty, clean shells to the bed to serve as a foundation to which the spat can adhere.

References

Cronan, C. S. "Clam Shells Kill Waste Acid." *Chemical Engineering*, 67:12, 78. 1960.

McKee, L. G. "The Oyster, Clam, Scallop, and Abalone Fisheries." In Stansby, M.E. (ed). *Industrial Fishery Technology*. Reinhold Publ. Co., New York. 1963.

Nelson, D. J., T. C. Rains, and J. A. Norris. "High-Purity Calcium Car-

bonate in Freshwater Clam Shell." *Science, 152*:1368-1370. 1966.
Shearon, W. H., Jr. "Oyster Shell Chemistry." *Chemical & Engineering News, 29*:21, 3078-81. 1951.
Soderquist, M. R., K. J. Williamson, G. I. Blanton, Jr., D. C. Phillips, D. K. Law, and D. L. Crawford. *Current Practice in Seafoods Processing Waste Treatment* (Water Pollution Control Research Series, 12060 ECF 04/70). U.S. Environmental Protection Agency, Washington, D.C. 1970.
Tressler, D. K., and J. McW. Lemon. *Marine Products of Commerce.* Reinhold Publ. Co., New York. 1951.

5.153 MISCELLANEOUS FISHERY BY-PRODUCTS

The most important by-product of fish processing is by far the production of pet foods. In many plants pet foods are almost as important as the primary processed fish, while in some plants pet foods are the primary product. Either the accumulation of scrap portions, such as the heads, viscera, skins and trimmings, or the entire fish is used. These materials are often mixed with cereals, yeast, egg yolks, or vitamin and mineral supplements in proprietary cat and dog food formulations.

The roe removed from harvested female fish may be a valuable by-product. Salmon eggs are considered a delicacy by many ethnic groups and are expressly collected in Alaskan salmon canneries for export to Japan. Roe is also used as feed in aquaculture and, in the case of salmon eggs, preserved and widely used for bait in sport fishing.

Oils recovered from some fish species, especially from the liver, have served as important sources of vitamins in the human diet. Most notable has been the use of cod liver oil as a source of Vitamins A and D. However, other sources of these vitamins have largely replaced fish oils for this use.

Guanine crystals isolated from fish scales, primarily herring, are suspended in lacquer and marketed as pearl essence. Pearl essence, when used as a spray coating or a dip, imparts an iridescent sheen similar to that of pearls. Thus, it is widely used for numerous decorative items, textile finishes, and the manufacture of artificial pearls. Crude guanine, obtained by washing the scales, is digested with pepsin in an acid solution to remove protein. The recovered crystals are then suspended in a nitrocellulose ethyl acetate lacquer. The quality of the end product is largely determined by the minimal presence of proteinaceous impurities which require removal by digestion.

Skins from bottom fish, notably cod, have been used to manufacture fish glue. The skins are washed with water to remove salt and may be pretreated with caustic and neutralized with acid. Glue is produced by cooking the skins with dilute acid for several hours. The dilute glue is then concentrated in evaporators to the desired viscosity. Essences are usually added to give the final product a pleasing odor. Using good skins under carefully controlled conditions, a glue of extremely high quality can be produced. While fish heads and bones may also be utilized, the end product from these residuals will have less desirable characteristics.

A fish gelatin, called isinglass, has been manufactured from the air bladders, or sounds, of bottom fish. The sounds are thoroughly washed, air dried, moistened with water, and drawn into ribbons. Isinglass is an effective filtering aid and has been used to clarify wines.

With the exception of pet foods all of these by-products have a fairly limited market and each is individually of minor importance. However, where a market for each has been developed, the value has been significant to its producer.

References

Nelson, R. "Processing Animal Feed." In Stansby, M. E. (ed). *Industrial Fishery Technology.* Reinhold Publ. Co., New York. 1963.
Soderquist, M. R., *et al. Current Practice in Seafoods Processing Waste Treatment*. (Water Pollution Control Research Series, 12060 ECF 04/70). U.S. Environmental Protection Agency, Washington, D. C. 1970.
Stansby, M. E. "Miscellaneous Industrial Products." *Industrial Fishery Technology.* Reinhold Publ. Co., New York. 1963.
Tressler, D. K., and J. McW. Lemon. *Marine Products of Commerce.* Reinhold Publ. Co., New York. 1951.

5.2

DISPOSAL METHODS

Disposal of food processing residuals with the creation of little or no environmental problems requires a great deal of care and good management practices. The high moisture content and readily putrescible nature of food residuals pose special problems which must be considered when handling and disposing of these materials. For example, if food residuals are held for prolonged periods, they will begin to decay, giving rise to offensive odors and attracting insects. Such a condition will create sanitation problems at the processing facility. If residual materials are improperly disposed of, leachate (seeped liquid) from the waste mass can contaminate surface and underground waters, as well as creating nuisance conditions of malodors and pest attraction.

Recommended handling procedures and disposal practices, as well as problems experienced by the industry, are discussed in this section. These can serve as guidelines when implementing solid waste management programs, improving existing procedures, or adopting alternatives.

5.21 Management of Solid Residuals

Whether solid food processing residuals are to be utilized or disposed of, good management practices must be observed to preclude the development of nuisance conditions. Considerations must be given to (1) procedures used to handle residual materials from the point of generation within the plant, (2) on-site facilities provided to temporarily accumulate and hold the materials, (3) equipment used to transport the residuals to the utilization or disposal site, and (4) procedures for properly disposing of solid wastes.

Several in-plant procedures for handling solid residuals are described in Section 2.3; removal of solids from untreated wastewater is discussed in Section 4.11. The following discussions pertain primarily to the management of food residuals from these sources.

5.211 ON-SITE HOLDING FACILITIES

Information was elicited during a recent study[1] on industrial practices of accumulating and "storing" solid residuals prior to hauling from the plant. The methods commonly employed, reported as percentages of plants by region, by product class, and by plant size, are summarized in Table 5.03.

5.2111 Stockpiling

Accumulating and holding residual materials in stockpiles is the method least employed by the industry, due largely to environmental problems associated with this practice (see discussion below). Whenever possible, this method should be avoided. However, if stockpiling is deemed necessary, even on a temporary basis, certain measures should be provided to minimize possible problems.

1. Areas in which materials are to be piled should be paved, preferably with conceete.
2. Curbs and/or gutters should be provided around the periphery of the slab.
3. The slab, as well as any gutters, should be graded to enable the collection of seeped liquid at a central location. A sump equipped with a level-controlled pump should be provided to pipe accumulated liquids to the plant wastewater disposal system.
4. Stockpiled materials must be removed as quickly as possible. In no case should food residuals be allowed to sit for more than 24 hours. The slab should be washed down immediately each time materials are removed.

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[1] Katsuyama, A. M., N. A. Olson, R. L. Quirk, and W. A. Mercer. Solid Waste Management in the Food Processing Industry (PB-219 019). U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA. 1973.

TABLE 5.03
ON-SITE RESIDUALS HOLDING FACILITIES
(percentage of plants)

On-Site Facility	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alaska	Sou. West	Total
Stockpiles	8	4	9	8	7	4	4	0	1	5
Port. contnr.	38	44	49	37	37	30	45	100	46	42
Perm. hopper	8	29	25	31	26	43	43	0	46	36
Trucks	46	23	23	24	30	22	8	0	8	16

	Fruit	Tomato	Vegetable	Seafood	Specialty
Stockpiles	3	4	5	13	5
Port. contnr.	47	36	38	63	50
Perm. hopper	39	49	38	0	27
Trucks	11	10	20	23	18

	Plant Size, 1000 raw tons/year					
	0–1	1–5	5–25	25–100	100–200	Over 200
Stockpiles	5	5	5	6	5	7
Port. contnr.	64	49	38	40	38	40
Perm. hopper	5	22	38	40	38	53
Trucks	27	24	18	15	20	0

The measures, of course, do not apply to the stockpiling of non-food residuals, such as wood and cardboard. However, it is recommended that even these nonputrescible materials not be piled in open areas. They provide excellent harborages for insects and rodents and can become scattered, creating aesthetically objectionable conditions around the processing facility.

5.2112 Portable Containers

Portable containers are used most widely to accumulate and hold residuals for hauling. These include barrels, boxes, wheelbarrows, bins, portable hoppers, and portable trash compactors. Generally, several types of containers are used. Barrels and boxes, or similar small containers, are used to collect solid residuals from various operations. These are emptied into larger containers, such as bins or portable hoppers located in different operational areas of the plant. The larger containers are then transported to a central location to await hauling vehicles, or are in turn emptied into even larger containers, such as a drop box, for holding and hauling. Alternatively, mechanical or hydraulic conveying systems are used to transport residuals to a central location where the solids are deposited directly into the large containers.

The major advantage of containers is the flexibility afforded by their portability and their relatively low costs. Containers can be readily moved from place to place as demands dictate, eliminating the need for expensive, fixed mechanical conveying systems. They are "modular" in that more or fewer units can be used to meet fluctuating needs. The major disadvantage is increased labor required to handle the containers, especially the smaller sizes.

Observing a few precautions will assure that environmental problems are minimized when using containers.

1. Small containers used to handle residuals in the processing areas must not be used to handle raw products intended for packaging. The chances for food products to be placed into waste containers can be minimized by painting such containers a distinctive color.
2. Residuals accumulated in containers must not be allowed to set for prolonged periods. Containers used for this purpose should be leakproof. These containers should be emptied and the materials hauled from the plant at least once per day. Whenever possible, containers awaiting hauling vehicles should be covered.
3. All waste containers should be washed regularly, preferably at least once per day. Both the interior and exterior surfaces must be cleaned.
4. Containers should be held on a paved area. The area must be kept free of spilled materials and hosed regularly.
5. Each container should be used for handling only one type of material, such as food residuals, non-food wastes, or metals, to facilitate recycling and disposal. Color-coding and labeling all containers will help.

The Dempster Dumpster®, or equivalent large portable bin with a hinged cover, is ideal for accumulating solid residuals. This unit is specifically designed for quick emptying into appropriately equipped garbage trucks. This container is especially useful for storing all types of non-food wastes and smaller quantities of food wastes.

For larger quantities of food wastes, drop boxes are very convenient. They can be quickly loaded onto suitably designed trucks. Raised platforms should be provided for these boxes to minimize spillage that may otherwise occur during pick up by the trucks. By eliminating the need to compensate for tilting, a larger percentage of the box capacity can be utilized. For convenience of emptying, drop boxes should be constructed for end discharge. The door or end-gate must be tightly sealed to prevent leakage of product juices that will inevitably be released from food residuals.

5.2113 Permanent Hoppers

Elevated hoppers are used by plants of all sizes. Solid residuals are deposited into the hoppers by bucket elevators, drag or screw conveyors, or pneumatic systems. Where residuals are hydraulically handled, screens are often installed above the hopper to separate solids from the water and the residuals are discharged directly from the screens. A sliding gate, either mechanically or manually operated, is opened to discharge accumulated solids directly into hauling vehicles.

Permanent hoppers are especially suitable for handling large quantities of food residuals. However, they can be designed and readily constructed to any size. Permanent hoppers minimize labor required for on-site handling of food residual materials but are not suitable for bulky non-food items. Although they are relatively costly, their convenience often more than justifies the expense.

Since stored food residuals will release product juices, the area surrounding elevated hoppers should be paved and graded to collect any drippage. The pavement, as well as the exterior of the hopper, should be hosed regularly to prevent odor development and insect attraction. The hopper should be emptied frequently, with special attention given to assuring that pieces of debris do not collect on support braces and other appurtenances.

5.2114 Trucks

Trucks are used to accumulate, as well as to haul, product residuals. Dump trucks are normally used for solid residuals, while tank trucks are used for fluid materials. Solids are usually collected in containers which are emptied directly into the truck; liquids, such as juice settlings, are pumped directly to the tanker. Although this is a convenient method for handling small volumes of wastes, it may not be practical for managing large quantities of steadily-generated residuals unless a fleet of vehicles can be provided. The use of permanent hoppers or drop boxes, or storage tanks in the case of liquids, will reduce the number of vehicles required by providing holding capacities between trips.

Dump trucks, or other rear discharge vehicles (such as manure trucks), can be conveniently put to dual use. However, the rear gate must be water-tight since leaking fluids can cause roadways to become dangerously slick. Watertight seals are mandated for such vehicles in many states.

5.2115 On-Site Problems

Information on environmental problems associated with the various on-site holding facilities was also elicited during the previously-cited study. The results, reported as a problem frequency index, are summarized in Table 5.04.

TABLE 5.04
HOLDING FACILITIES AND PROBLEMS
(frequency index)

Problem	Stock piles	Port. Contnr.	Perm. Hoppers	Trucks
Leaching	37	37	31	23
Seeping	27	31	27	26
Insect	94	77	68	57
Rodent	59	48	39	32
Odor	36	24	20	23

Leaching (defined in the study as separation of liquid from solids) and seeping problems were experienced with all types of holding facilities without significant relation to the method. However, insect, rodent, and odor problems were most prevalent for stockpiling and least for trucks. These problems are attributable to the high moisture content and putrescible nature of food residuals. Although little can be done to control liquid separation, problems associated with seeping, insects, rodents, and odors can be minimized to a great extent by strict adherence to good housekeeping practices.

1. Accumulated food residuals should be hauled from the plant at frequent and regular intervals. Prolonged storage will only aggravate all of the listed problems.
2. Spilled materials must be picked up immediately and properly disposed of.
3. Residual receptacles and handling areas should be washed regularly.

Additionally, insect control programs, including dusting or spraying, should be practiced regularly. When problems arise, the frequency of residuals hauling should be increased, attention to housekeeping intensified, and spraying frequencies increased. Rodent controls, including the proper use of baits and traps, should also be routinely practiced. Evidence of increased rodent activity should be countered with increased surveillance and controls.

Since insects and, to a lesser extent, rodents will inevitably be attracted to food residuals, handling areas should be located away from the processing facility. By locating this area in a remote site, the likelihood of plant sanitation problems developing from this source will be greatly minimized. Furthermore, remote locations will enable greater flexibility in dealing with problems that may arise.

5.212 DISPOSAL PRACTICES

The common disposal methods for food processing residuals are described in Section 1.2323. Most food processing residuals are disposed of on land, either in landfills or by spreading; these procedures are described in detail below. A small quantity of non-food residuals are burned and an even smaller quantity (largely seafood residuals) discharged to receiving waters.

5.2121 Burning

Incineration of combustible, non-food residuals, either on plant premises or elsewhere, is practiced by relatively few plants (Table 5.05). Undoubtedly, increasingly stringent air pollution regulations will result in even fewer plants employing this once-common method of solid waste disposal. Furthermore, the bulk of combustible non-food residuals is cardboard, paper, and similar materials which are being increasingly recycled (see Section 5.11).

Among those plants that burned, periodic burning (less than once per day) in open fires was the commonest method. Among those few plants which used furnaces or incinerators, burning was conducted either periodically or more than once per day.

Burning offers the advantage of greatly reducing the volume of solid wastes, especially with such bulky materials as scrap lumber, thereby reducing the rate at which land disposal sites are filled. Ashes are also generally more manageable than bulky items. Where burning is permitted and deemed to be desirable, the use of a furnace or incinerator is recommended. However, caution must be exercised to assure compliance with any air pollution regulations that may exist.

TABLE 5.05
ON-SITE BURNING
(percentage of plants)

Type of Burning	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alas-ka	Sou. West	Total
None	92	78	70	69	72	80	78	75	73	74
Open										
<1/day	8	12	9	10	6	10	13	5	12	11
>1/day	0	2	9	9	0	0	5	20	1	5
Furnace										
<1/day	0	0	6	3	0	0	5	0	7	4
>1/day	0	7	6	8	22	10	0	0	7	6

From: Katsuyama, A. M., *et al. Loc. cit.*

5.2122 Disposal Sites

During the previously-cited solid waste management study, information was elicited on a variety of aspects of solid waste disposal sites. Although the data do not provide operational details, the information offers general guidelines to some of the alternatives employed by the industry in disposing of solid waste materials.

Ownership and Materials Handled. The type of ownership and materials handled at disposal sites are summarized in Table 5.06. More than half of the fill sites used by the industry are publicly owned and operated, while most of the spread sites are privately owned, either by the processor or by local farmers or other private parties. Burning sites are largely either on the processor's property or on publicly owned land.

Publicly owned fill sites are used for garbage, other industrial refuse, and other domestic refuse, in addition to food processing solid wastes, whereas fill sites owned and operated by processors and a few operated by other private parties are used exclusively for the processors' wastes. Spread sites are almost exclusively reserved for food waste disposal.

Location and Size. The distance from the processing plant and the number of acres occupied by the sites are summarized in Table 5.07 (percentages of reported sites). Most disposal sites are located less than 10 miles from the plant. However, fill sites in the South West and spread sites in the North West and South West are frequently situated farther than 10 miles.

About half of the fill sites and half of the spread sites are more than 10 acres and less than 100 acres in size. Spread sites, which are usually agricultural land, are larger on average than fill sites.

Type of Land. A variety of land types (Table 5.08) are used for the disposal of food processing wastes. Fill sites include pits (such as abandoned quarries), gullies, flatlands, marshes or tidelands, but very few agricultural or "wasteland" locations. A high proportion of spread disposal sites is expectedly on agricultural land. Differences between land types are geographically related and indicate that local practices are largely determined by land availability.

Discussion. The above information indicates that food processors dispose of solid wastes in a variety of locations. Public (including privately-operated) landfill sites offer a distinct advantage, especially to smaller facilities with lesser amounts of waste materials. Moderate fees, normally assessed on each delivered load, enable users to simply deposit refuse at the site without regard for its management. Collected fees are used to defray operating expenses and, in the case of private operators, provide profits. Public landfill sites are generally located within short distances from most populated areas, offering the added advantage of convenience and accessability. However, limitations may be imposed upon the quantity of food residuals accepted at some sites – a few have refused loads of very wet wastes, such as slurries of ground fruit residuals. When considering the use of a public landfill site, initial inquiries should be made regarding the acceptability of the plant's solid waste at that site.

A number of processors manage the disposal of their own wastes, utilizing either company owned or private land. The distances between plants and disposal sites vary widely and will be dictated primarily by the availability of suitable land. No specific type of land is required for landfill operations and the size of the site will be determined by the quantity of materials that must be disposed of. However, certain practices must be followed to obviate the development of environmental problems. Detailed considerations for landfill disposal are discussed later.

Spreading of food residuals on agricultural or other land is a disposal practice gaining in popularity among processors who manage their own wastes. This is often done with the cooperation of neighboring farmers but may be conducted on company-owned property by plant personnel. This highly effective method is essentially a recycling practice that can result in marked improvements in the soil. A detailed description of one operation is provided later in this section.

5.2123 Disposal Site Problems

Data were developed during the solid waste management study on problems experienced at disposal sites. Information based on relatively few sites are reported in Table 5.09 as frequency indices. These do not reflect the actual frequency in which problems occurred nor the severity of the problems at the reporting sites. They do, however, indicate the relative occurrence of the listed problems.

Generally, all landfill sites utilized by food processors experience some problems with insects, rodents, and odors, although some problems are greater than average in certain parts of the country. Sites used by smaller processors tend to experience a higher proportion of problems. Water pollution problems due to leachate from landfill sites are relatively uncommon except in Alaska (where only non-food wastes are disposed).

TABLE 5.06
OWNERSHIP OF AND MATERIALS HANDLED AT DISPOSAL SITES
(percentage of plants)

Owned,	Operated by:	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alas-ka	Sou. West	Total
Fill	Processor	0	38	19	18	0	17	15	0	7	15
	Private Co.	20	28	23	38	18	0	21	0	42	31
	Public	80	34	58	44	82	83	64	100	51	53
Spread	Processor	–	38	50	25	25	33	18	67	22	29
	Private Co.	–	52	42	75	75	67	82	0	56	63
	Public	–	10	8	0	0	0	0	33	22	8
Burn	Processor	0	33	70	42	50	50	38	67	39	45
	Private Co.	0	0	10	25	0	0	0	0	17	12
	Public	100	67	20	33	50	50	62	33	44	43
Materials Handled											
Fill	Processor only	0	41	11	27	0	33	13	0	8	18
	Garbage	60	31	44	58	73	17	69	100	51	54
	Ind. refuse	60	41	41	55	55	67	44	50	66	53
	Dom. refuse	80	34	37	51	45	50	31	50	45	43
Burn	Processor only	0	33	60	42	50	50	25	0	39	38
	Garbage	0	0	30	50	0	0	62	100	39	40
	Ind. refuse	50	67	30	67	50	0	75	0	50	50
	Dom. refuse	50	0	0	42	0	0	12	100	33	27

Problems at spread sites vary widely, not only between regions but also between types of problems. Odors and insects are most frequently experienced, but water pollution problems are rarely encountered at spread sites. The data indicate that insect problems increase in frequency with increasing plant size.

Problems experienced at burn sites are highly variable. Although the number of sites in the sample is too small to show significance, insect problems for fruit plants are apparently high. Overall, insect and rodent problems appear to be less frequent and odor problems more frequent at sites that burned than at fill sites.

Problems experienced at disposal sites operated by food processors, by private companies, and by public agencies are reported as frequency indices in Table 5.10. Insect problems are encountered at all of the reported sites. Rodents and odors occur with significantly high frequency at publicly operated fill and spread sites. On the other hand, rodents and odors appear to be less of a problem at processor and privately operated fill and at privately operated spread sites.

Fill disposal sites are also often used for garbage and/or industrial and domestic refuse disposal. Problem frequencies at sites handling these classes of materials are also reported in Table 5.10. Insect problems are experienced with equal relative frequency at all sites, but rodents and odors are significantly less of a problem at fill sites handling only food processing residuals.

Although public landfill sites are convenient, the listed problems are inherently prevalent at these sites. The operators (public agencies), rather than the users, are responsible for controlling these problems. Nevertheless, processors utilizing sites where problems commonly occur are advised to work closely with responsible agencies to assure that food residuals are handled in a manner whereby they are not contributing factors. Public health departments can and have closed land disposal sites, causing users to scurry for alternative locations. It would be prudent for processors to have contingency plans to cover this likelihood.

Processors who operate their own disposal facilities are responsible for controlling any problems that may arise. The development of serious problems can be greatly minimized by careful management. Recommended practices are described later in this section.

5.213 HANDLING AND DISPOSAL COSTS

Capital costs for in-plant solid residuals handling are incurred for equipment, such as conveyors, containers, hoppers, trucks, and other miscellaneous items. A conservative estimate of the total capital costs, on average, for the industry is \$1.20 per ton of raw product, or \$0.12 per ton per annum for a 10-year amortization. Actual individual plant costs vary widely. Additionally, operating and maintenance costs, including labor, average about \$0.17 per ton per year, resulting in an average total annual in-plant cost of \$0.29 per ton of raw product.

Out-of-pocket expenses are incurred for solid waste hauling and disposal sites. Information from the solid waste study is summarized in Table 5.11. Although individual plant costs again vary widely, seafood plants and small tomato plants have lower than average costs and specialty foods plants have apparently high costs. Economies of scale, based on costs per ton, are evident. The annual industry average is \$0.40 per ton of raw product.

Differences exist in costs between the types of disposal sites employed by plants (Table 5.12). Generally, costs are lower when residuals are disposed of exclusively by spreading rather than by landfill. Disproportionate costs are incurred by the smallest plants using both fill and spread and by plants processing between 25,000 and 100,000 tons per year and using spread sites. Otherwise, economies of scale generally apply.

TABLE 5.07
LOCATION AND SIZE OF DISPOSAL SITES
(percentage of plants)

	Miles to Site	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alas-ka	Sou. West	Total
Fill	<1	0	14	11	20	0	17	12	0	3	11
	1-9	100	72	70	70	82	83	76	100	59	70
	10+	0	14	18	10	18	0	12	0	38	18
Spread	<1	–	35	17	17	25	33	10	0	0	15
	1-9	–	60	83	78	75	67	50	100	52	68
	10+	–	5	0	5	0	0	40	0	58	17
Burn	<1	0	33	70	42	50	50	38	0	38	41
	1-9	100	67	30	50	50	50	62	100	44	52
	10+	0	0	0	8	0	0	0	0	19	7
Acres at Site											
Fill	<10	25	28	75	20	11	20	29	50	5	23
	10-99	75	52	19	61	55	80	50	50	44	51
	100+	0	20	6	19	33	0	21	0	51	26
Spread	<10	–	18	27	8	0	0	11	100	11	14
	10-99	–	65	55	51	100	100	44	0	44	52
	100+	–	18	18	41	0	0	44	0	44	34

5.22 Landfill

Land disposal has historically been the conventional method for disposing of garbage and other solid wastes. Until recent years the common procedure was to simply fill an excavated pit or a natural land depression (gully, ravine, etc.) with refuse, often accompanied by the burning of combustible materials. When the site became filled to capacity, the deposited materials were buried by covering the area with soil. This procedure has popularly been referred to as open dumping. A more recent technique, referred to as sanitary landfill, calls for frequent compaction and covering of wastes deposited at the site.

Numerous environmental, health, and safety problems have been associated with open dumps. Strong malodors and smoke (where burning is done) has been typical air pollutants. Leachates containing high contentrations of dissolved organic and inorganic matter, including heavy metals and other toxic substances, have contaminated both surface and underground waters; this problem has been especially acute following rainfalls at some sites. Not only are dumped solid wastes unsightly, but unaesthetic conditions around open dumps have been commonly compounded by wind-strewn debris. Public health problems have been attributed to open dumps by virtue of their inherent attraction of insects, rodents and birds – all are natural vectors. Filled dump sites have little utility since the covered wastes are unstable and prone to uneven settling. Spontaneous combustion of buried materials has occurred at some old sites, posing safety and health hazards. These problems have led to the recent ban of new open dumps and the requirement that existing open dumps be closed or upgraded.[1]

On the other hand, sanitary landfill techniques are designed to prevent the problems associated with open dumping. Sites are engineered to protect surface and ground waters, either through natural geologic conditions or by appropriate site preparations. All deposited refuse is compacted and covered with soil at least once daily, thereby minimizing the generation of leachate and odors, attraction of vectors, and scattering of debris. The Resource Conservation and Recovery Act of 1976 has extended the definition of sanitary landfill from this traditional procedure to now include all landfill

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[1] Resource Conservation and Recovery Act of 1976 (P.L. 94-580 enacted on October 21, 1976). 42 U.S.C. 3251 *et seq.*

TABLE 5.08
TYPES OF LAND FOR DISPOSAL SITES
(percentage of plants)

Type of Land	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alas-ka	Sou. West	Total
Fill Sites										
Pit	60	8	30	25	20	17	17	0	11	19
Gully	20	12	25	20	30	50	56	100	33	32
Level	20	62	40	39	50	33	21	0	36	37
Marsh, Tidal	0	8	5	12	0	0	4	0	20	11
Agricultural	0	4	0	4	0	0	0	0	0	2
Waste	0	4	0	0	0	0	2	0	0	1
Spread Sites										
Agricultural	–	76	80	91	75	100	73	0	76	83
Waste	–	12	10	9	25	0	18	0	19	13
Other	–	12	10	0	0	0	9	100	5	4

TABLE 5.09

DISPOSAL SITE PROBLEMS

(frequency index)

Problem	New Eng.	Mid Atl.	Sou. Atl.	Nor. Cent.	Sou. Cent.	Mtn.	Nor. West	Alas-ka	Sou. West	Total
Fill Sites										
Insect	25	72	82	54	100	100	35	50	53	58
Rodent	100	44	88	46	75	67	56	100	44	55
Odor	50	67	47	49	88	33	46	50	37	49
Water Pollution	0	6	0	6	0	0	8	50	5	6
Spread Sites										
Insect	–	47	50	21	100	–	14	0	86	42
Rodent	–	21	20	5	0	–	14	0	32	15
Odor	–	60	60	40	100	–	57	100	52	52
Water Pollution	–	0	0	2	0	–	0	0	0	1
Burn Sites										
Insect	–	0	71	36	50	100	50	0	40	44
Rodent	–	100	57	55	0	100	33	0	40	44
Odor	–	100	71	55	50	100	50	100	50	61
Water Pollution	–	0	0	18	0	0	17	0	0	7

sites that meet the criteria of acceptance promulgated by the Administrator of the Environmental Protection Agency.[1] Sites meeting the minimum criteria for determining that a solid waste land disposal facility poses no reasonable probability of adverse effects on health or the environment will be classified as a sanitary landfill site regardless of the specific procedures followed at that site.

Open dumping of food processing residuals has accentuated some of the problems inherent to this disposal method. The putrescibility of the organic matter has compounded insect and odor problems at many sites; the high mositure content of food residuals has increased leachate generation. These problems have been especially severe at open dump sites used exclusively for food processing wastes. The filling of pits or trenches with food residuals, followed by covering with soil, has additionally created a unique, severe problem. Under the conditions created by this practice, food wastes – especially high-acid (fruit) residuals – have undergone anaerobic fermentation, resulting in the "pickling" of deposited materials. When some pits or trenches have been uncovered, even after several years of burial, food particles virtually unchanged in physical appearance have been discovered. Thus, open dumping of food processing residuals must be avoided. Instead, sanitary landfill (or land spreading) is strongly recommended.

5.221 CONSIDERATIONS IN SITE SELECTION

When sanitary landfill disposal of food processing residuals is considered, a processor will usually have two options. First, he may explore the possibility of utilizing a near-by public site or, second, he may wish to conduct or have conducted an operation reserved exclusively for his wastes. In either case careful considerations must be given to site selection.

5.2211 Use of Public Landfill Sites

The use of a public site, whether operated by a public agency or private company, offers several distinct advantages to the processor. Most processing facilities are located within short distances to a disposal site where the operators are responsible for the management of delivered wastes. Usually

TABLE 5.10

PROBLEMS vs OWNERSHIP AND MATERIALS HANDLED

Problem	Fill Sites			Spread Sites		
	Owned, Operated by:					
	Processor	Private	Public	Processor	Private	Public
Insect	50	50	55	46	44	55
Rodent	41	40	70	23	17	44
Odor	33	38	63	63	42	75

Problem	Material Handled at Fill Site		
	Processor's Only	Include Garbage	Include Refuse
Insect	58	51	52
Rodent	28	66	58
Odor	36	58	50

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[1] Solid Waste Disposal Facilities – Proposed Criteria for Classification." 43 *FR* 4942-4955. February 6, 1978.

TABLE 5.11
ANNUAL HAUL PLUS SITE COSTS

Product Class	Annual Costs, x $100					
	Plant size, 1000 tons per year					
	0–1	1–5	5–25	25–100	100–200	Over 200
Fruit	.5	1.4	5.9	19.8	25.2	14.0
Tomato	0	.8	6.4	17.8	23.1	46.1
Vegetable	1.2	3.9	5.1	14.0	22.4	29.8
Seafood	.7	.4	4.3	–	–	–
Specialty	.7	3.4	12.2	24.9	24.0	65.4
ALL	.7	1.9	6.4	17.6	23.5	32.0

for a modest fee, users of such sites can dispose of their wastes without regard for operational and environmental problems. Garbage and other solid wastes normally handled at public sites will assist in the landfill disposal of high moisture food residuals by acting as absorbants.

However, the nature of food residuals mandates the processor to explore the acceptability of his wastes at public sites prior to actual delivery. Information on the total quantity and character of the wastes and on the schedule and quantity of waste deliveries should be provided by the processor during initial discussions. With this information the operator should be able to ascertain whether or not the site can accommodate the additional load and what limitations, if any, will have to be imposed on deliveries from the processing plant.

The food processor can assist in the disposal of his wastes at a public site by observing a few simple precautions. Where possible, several deliveries of smaller quantities, rather than fewer deliveries of large quantities, should be made. Each load should be discharged over as wide an area as possible, rather than dumping the wastes in a concentrated pile. These observations will aid in avoiding "pockets" of food residuals, thereby minimizing the possibility of creating unacceptable environmental problems that will inevitably lead to preclusion of food wastes from the site.

5.2212 Sites Exclusively for Food Residuals

Responsibility for management of a landfill site used exclusively for the disposal of food residuals will generally rest with the processor, even when a private operator is employed. Therefore, sites must be selected for this purpose with extreme care to assure no liabilities result from health and environmental problems.

TABLE 5.12
HAUL PLUS SITE COSTS FOR FILL AND SPREAD DISPOSAL

Type Disposal	Annual Costs, x $1000			
	Plant size, 1000 tons/year			
	0–5	5–25	25–100	Over 100
Fill (only)	1.9	9.3	15.3	35.6
Fill and Spread	3.9	5.6	18.7	25.0
Spread (only)	1.1	5.0	21.6	15.0

Geologic and Hydrologic Considerations.[1] All sanitary landfills must be engineered to prevent surface and ground water pollution. This can be accomplished either by the leachate (1) being naturally renovated while percolating through the underlying earth materials or (2) the leachate being collected and treated like other wastewaters.

The geologic and ground water conditions at each site must be known before a decision can be made whether to design for natural renovation or for collection and treatment. Geologic conditions that must be determined include (1) the kind of bedrock; (2) degree of weathering of the bedrock; (3) breaks (discontinuities) in the bedrock from faults, joints, open bedding planes, and solution openings; and (4) permeability (ability to allow liquids to flow). Ground water conditions to be determined are (1) depth to ground water, (2) chemical quality of the ground water, (3) direction and rate of ground water movement, and (4) discharge points of the ground water.

For natural renovation the rock should be deeply weathered, moderately permeable, sufficiently above ground water, and have few or no discontinuities. For collection and treatment the bedrock should be very tight (low permeability) with no discontinuities and there should be a lack of connection with the underlying ground water. The geologic and ground water conditions must be determined by trained, experienced geologists and hydrologists.

The above considerations are especially important when dealing with moisture-laden food residuals. However, sites which do not meet these conditions but are otherwise suitable for land disposal can be engineered for the intended use. Protection of water sources, the primary concern, can be accomplished by lining the sides and bottom of the site with compacted soil (notably heavy clays) and/or installing a suitable underdrain system. In such situations the services of a recognized professional will usually be required.

Location. Since lands in close proximity to developed areas command premium prices, economics will normally dictate that disposal sites are located in relatively isolated or remote areas. Such locations are, of course, desirable for minimizing environmental and aesthetic concerns. However, consideration should also be given when selecting a landfill site to future potential uses of the land. Generally, old sites that have been properly filled will be suitable for agricultural, forestry, or recreational uses, but not for construction of buildings or public roadways.

The EPA criteria for classification of solid waste disposal facilities impose stringent requirements for landfill sites on wetlands, floodplains, permafrost areas, critical habitats of endangered species, and other "environmentally sensitive areas." All new sites will require the development of environmental impact reports and the acquisition of permits from local and state regulatory agencies.

Cover Soil Availability. Soil in sanitary landfill operations serves four purposes:[2]

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1. Emrich, G. H. "Geology and Ground Water Considerations." Bureau of Sanitary Engineering, Pennsylvania Department of Health. Undated.
2. Loughry, F. G. "Solids in Sanitary Landfill Planning and Operation." Bur. of Housing and Environ. Control, Penna. Dept. of Health. April 1970.

1. Container. It furnishes the sides and bottom lining of trench and area landfills.
2. Cover. It is the common and most acceptable material for daily, intermediate, and final cover.
3. Renovator. It absorbs some decomposition products, it reacts directly with waste material to make new products, it retains material providing time and a favorable medium for change, and it filters original and degradation products.
4. Restorer. When used as final cover it supports vegetation to re-establish a green landscape with agricultural, forestry, or recreational uses.

Thus, sites being considered for sanitary landfill must have an adequate supply of soil for these uses or must be sufficiently close to a source from which an adequate supply can be economically hauled.

The type of soil used for daily covering of food residuals is not very important. However, it should be easily moved, easily compacted, and readily absorb moisture from the wastes. A sufficient supply to daily cover deposited materials at least two or more inches is desirable. Each final seasonal covering should be with a minimum of 10 to 12 inches of stable soil of medium texture, moderate permeability, and sufficiently compactable to resist erosion.

Detailed soil surveys, such as those produced by the U.S. Soil Conservation Service, can be used to screen potential landfill sites and eliminate the areas with seasonal high watertable, steep slopes, flooding hazard, extremely permeable substrata, and excessive stoniness. More detailed on-site investigations are usually required to furnish all the data needed for designing the fill and preparing operating plans.[1]

5.222 PROCEDURAL CONSIDERATIONS

Landfill procedures must be tailored to each operation, based on geologic factors at the site, the type of waste materials handled, topography, climatic conditions (primarily the extent of precipitation during operation), and the characteristics of the cover material. The primary concern must be to prevent the development of environmental and health problems that will jeopardize continuation of the operation. In this regard the following guidelines should be considered for all food processing waste landfill operations.

1. Each layer of deposited wastes should be evenly distributed over the site area. The depth of each layer should be such that any free moisture released from the materials will be absorbed by the cover material.
2. The cover material must adequately absorb free moisture. The depth of cover should be sufficient to contain all the waste liquid, thus eliminating the need for concern about escaping leachate. This consideration must be extended to containment of rain during periods of operation.
3. The wastes must be covered at frequencies sufficient to discourage insect breeding and rodent harborage. The thickness of the covering layer and its compaction should be sufficient to prevent exposure of putrescible waste materials and to suppress odors.
4. The covering at the end of each season should be at least 10 to 12 inches. This covering must be compacted sufficiently to resist erosion. Preferably, soils used for this covering should be relatively impermeable to rainwater, thus encouraging runoff and decreasing the likelihood of percolate-caused leachate escaping from the site. The filled area should be sloped to direct the runoff to an area designed for its control.
5. The final covering of the site should be with soil of adequate fertility to support vegetation. This covering must be well compacted and sufficiently deep to support potential future activities designated for the area.

5.23 Spread on Land[1]

Returning agricultural wastes to soils by spreading and discing is widely practiced to improve soil tilth and fertility while disposing of crop residues. This practice has been adopted for disposing of fruit and vegetable processing residuals from canning and freezing operations. However, the nature and quantity of materials handled at a site used exclusively for food processing residuals require special attention and equipment to preclude creation of nuisance conditions. Procedures developed in 1970 by a group of canners are being successfully employed by increasing numbers of plants to manage large quantities of food processing residuals in an environmentally-sound manner. These procedures, coupled with modifications by others, are described in this section to serve as guidelines for those who may wish to consider adopting this proven method of waste disposal.

The operation is basically one of good applied farming practices—it can be considered as the "farming" of food residuals, consisting of preparing the soil and working the disposal "crop" and land in a prompt and thorough manner. With careful and constant attention most food processing residuals will be readily assimilated into the soil without creating environmental problems. As a result of this operation definite improvements in soil tilth and crop productivity will be achieved.

The spread-and-disc operation can be conducted virtually on any type of workable soil in all but extremely wet areas. Most operations are on relatively flat land, ranging from heavy alkaline clay soils of a dry lake bottom and a fallow land sink to sandy loam of fertile, productive farms. With modifications of the spreading equipment (described below), the spread-and-disc operation can also be conducted on hilly land.

The solid residuals handled at existing sites are primarily from the processing of fruits (apricots, peaches, pears) and tomatoes. However, the procedures are suitable for disposing of all fruit or vegetable residuals. A specific program must be developed for each site, with consideration given to soil characteristics, climatic conditions, topography, and the nature of residual materials handled. Loading rates will also be influenced by the method and diligence of spreading and working. These factors will determine the size of site required to meet the needs of each plant.

5.231 EQUIPMENT

Basic farming implements are all that is required to conduct a spread-and-disc operation. The size of each unit must be adequate to handle the anticipated peak loads at each site. The

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[1] Loughry, F. G. "Soils in Sanitary Landfill Planning and Operation." Bur. of Housing and Environ. Control, Penna. Dept. of Health. April 1970.

[1] Based on procedures developed by the Cooperative for Environmental Improvement (CEI), Inc. and modifications by others. For additional information, write to CEI, Inc., 1007 "L" St., Sacramento, CA 95814.

following equipment can readily handle several hundred tons of residuals per day. An additional tractor and driver can more than double the capacity of the operation.

5.2311 Tractor

The tractors used at present sites are four-wheel drive units (John Deere, International Harvester, or equivalent), equipped with 26.00x28 single tires, as illustrated in Figure 5.11, or 18.40x38 dual tires. The wider single tires are especially suited for use in wet clay soils. "Track layers" are not recommended since this type of equipment tends to excessively mix the soil and residual materials, thus hampering drying.

5.2312 Spreading Devices

A suitable device to evenly spread deposited residuals is the single most important implement for a successful, nuisance-free operation, especially when dump trucks are used for delivering wastes to the site. A number of devices are being used for this purpose, including manure spreaders, grading and land planing equipment. However, the simplest and most effective apparatus is the tandem drag fabricated by the original developers of the spread-and-disc technique. The tandem drag is shown behind the tractor in Figure 5.11 and detailed in Figure 5.12.

The weight of the tandem drag is imporant – too heavy a drag will tend to move soil as well as the residuals, while too light a unit will simply ride over all materials. The illustrated drags were fabricated from 10-inch heavy wall (3/8-inch) steel pipe 18 feet in length. When operations are conducted on slopes, the lengths of the drags should be shortened as necessary to obtain even spreading.

Railroad iron (90#) was welded to the entire length of each pipe. Additionally, a five- to six-foot length of rail (116 pounds total weight) was welded to the back center of the rear drag. This piece, the actual length of which must be determined by trial-and-error, imparts a wobbling action to the rear drag; the motion facilitates spreading and crushing large fruit pieces. All ends of the pipes were capped with steel plates.

The two sections are connected by 46-inch lengths of one-inch chain. The connecting length is critical for proper spreading. The entire unit is connected to the tractor with 20 feet of one-inch cable and an appropriate coupling. The cable length is also critical to provide proper maneuverability of the tractor, especially when large piles are encountered. The connecting chains should be inspected frequently during operation. Special attention should be given to the first link behind the front drag and the first three links in front of the rear drag. These links will require replacing most frequently.

5.2313 Discs

The recommended discs, illustrated in Figure 5.13, are offset, not tandem, and equipped with notched blades. The unit is also equipped with four hydraulically-adjustable rubber tires to control the depth of cut. This is an essential feature to avoid excessive depths in wet soil. When operating on clay soils, the unit must be provided with additional weight. When maneuvering at the ends of a field, care must be exercised to avoid creating "dead furrows". Materials deposited in such furrows will anaerobically decompose, thereby creating odors and attracting flies.

A harrow with vibrating shanks is used with satisfactory results at one site. This type of equipment is suitable for use in

Figure 5.11. Four-wheel drive tractors in use at a spread-and-disc operation.

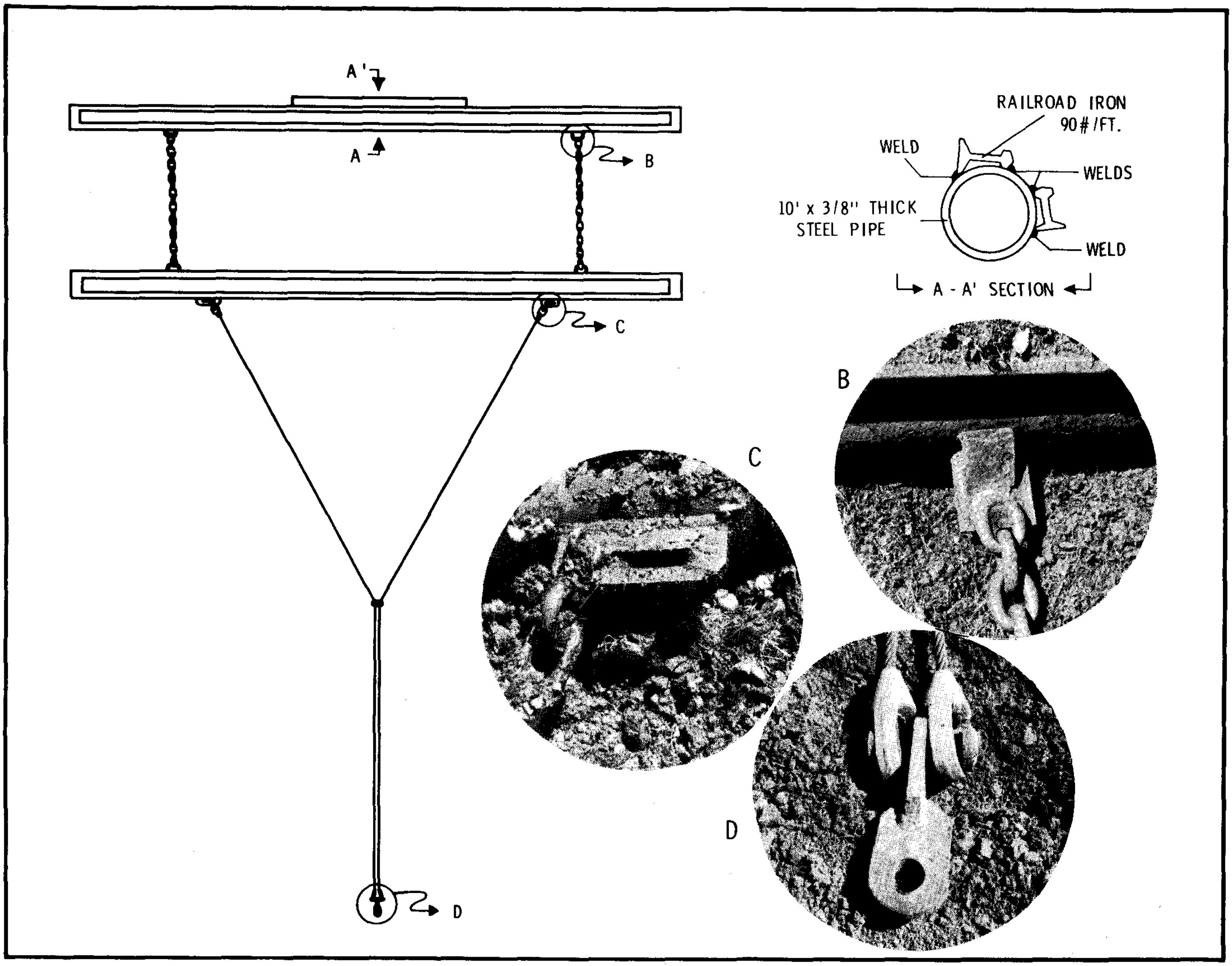

Figure 5.12. Detailed sections of the tandem drag.

lighter soils. Plows are generally not recommended since they tend to bury the spread residuals too deeply and thus hamper drying.

5.2314 Clod Breaker

Where soil characteristics dictate the need for breaking clods of soil, a Schmeizer of equivalent (Figure 5.14) should be provided. This apparatus not only evens out the soil texture but also helps to settle the soil, thereby enabling trucks to operate in the field without becoming bogged. Use of a clod breaker also facilitates spreading of residuals.

5.2315 Hauling Trucks

A variety of trucks are used to deliver food processing residuals to spread sites. These range from conventional dump trucks to tank trucks containing a slurry of ground material.

The ideal equipment is a rear-dumping bed with hydraulically-operated gates. With controls located inside the truck cab, close regulation of discharge rates is possible. Dump trucks without hydraulic gates must be carefully unloaded to avoid piles of moist materials. Chains used to limit the opening of the gates have not worked well as a means to regulate discharge rates because residual characteristics vary widely.

Long-bed trailers with up to 36 cubic yards capacity have posed problems with uniform discharging of loads and must be carefully operated. These have a tendency to tip or shift while unloading, thereby delaying site operations, increasing their costs, and increasing nuisance liabilities by creating "wet" piles. Bottom-dumping rigs are quite satisfactory since these are generally equipped with hydraulically-operated gates. Positive control provided by the hydraulic system enables these units to discharge materials in a narrow and uniform ribbon. However, most existing canneries cannot accommodate the double rigs.

When slurries of ground residuals are delivered in tank trucks, proper spreading (light and even distribution) is especially critical. A truck with a multi-valved discharge manifold should be used. If ground materials are discharged through a single valve, splash plates to spread the discharge should be provided.

At one plant where the spread-and-disc operation is conducted in an adjoining company-owned field, a truck equipped

Figure 5.13. Off-set discs equipped with notched blades.

with a manure spreader is used. By carefully controlling the rate of discharge and the forward speed of the truck, residuals are thinly and evenly deposited on the soil, thereby eliminating the need for a spreading device.

5.232 PRELIMINARY LAND PREPARATION

To maximize the receptive capacity of the soil and to minimize problems, the land must be prepared annually prior to disposition of any residuals. The soil should be worked to a depth of eight to ten inches with the discs. Compacted soils may require initial plowing. When large clods occur, a suitable clod breaker should be employed.

Although land planing is unnecessary, the soil surface must be leveled to the extent that no pocket holes exist. The tandem drag used for residuals spreading may also be used for this purpose. It is vitally important that all holes and furrows be filled before residuals are applied. This precautionary measure will eliminate the possibility of excessive accumulations of residuals and provide a uniform and moderately compacted surface for vehicular travel.

Preseason timing of the land preparation step is important. Unlike normal farming practices where soils are worked to retain moisture, land to be used for food waste disposal must be prepared to obtain maximum soil dryness. (Dry soil will have greater capacities for assimilating high moisture residuals.) This step is especially important when utilizing farmlands that have recently been harvested.

5.233 DELIVERY AND DISCHARGE OF RESIDUALS

Undue delays in deliveries must be avoided, especially with fruit residuals. When these materials are allowed to sit either at the processing plant or in an open truck, flies will inevitably be attracted and begin to breed. In such a situation fly problems at the disposal site will be unavoidable and difficult to control. Past experiences indicate that pear residuals quickly develop fruit fly populations and must be handled quickly.

Non-food residuals (cans, wood, metal scraps, and paper) must be absolutely precluded from the loads. The materials will interfere with the field operations and equipment and will hamper subsequent agricultural uses of the land. The site manager must be given full authority and responsibility to control delivered materials. He must be able to inspect the loads for extraneous materials and to refuse acceptance if such debris is present.

When residuals from numerous canneries are being delivered by several contract haulers, it is virtually impossible to schedule deliveries to the site. Therefore, a full-time field supervisor is required, especially during the peak of the season. The supervisor must be responsible for directing each truck to the appropriate spot in the field and assure that each load is properly discharged and spread.

Discharge lanes should be located on no less than 20-foot centers. The discharge of each load should be started sufficiently beyond the end of the previously deposited load to

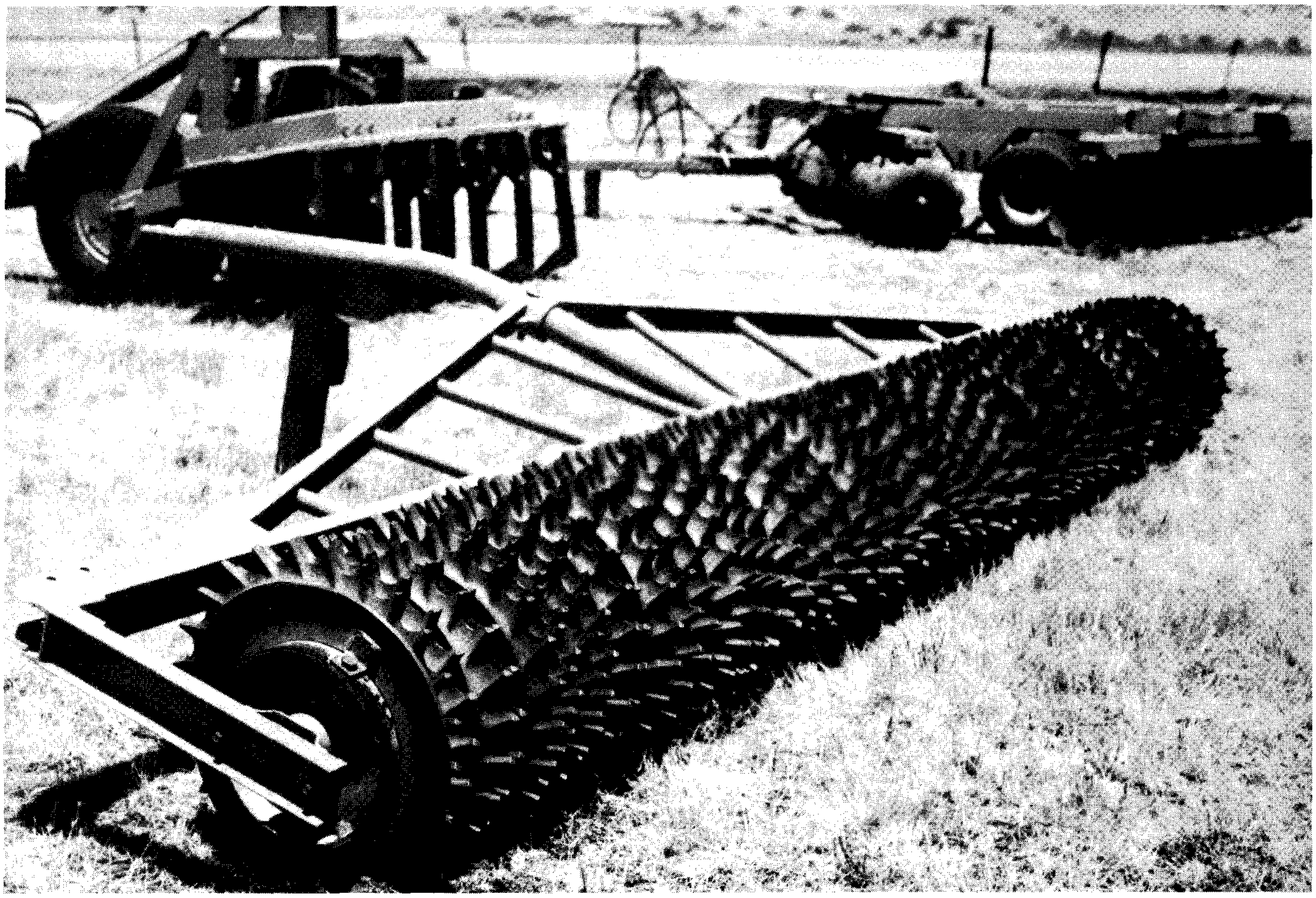

Figure 5.14. The Schmeizer is helpful in leveling out and settling the soil.

avoid overlapping of materials during spreading. The residuals must be discharged from the trucks as thinly and evenly as the equipment and the driver's skill allow (Figure 5.15). The materials must not be deposited in piles. Free moisture will seep from piled residuals making it extremely difficult to dry the soil at that spot. These wet spots, popularly referred to as "hot spots," generate odors and provide ideal conditions for fly breeding. Piles delay field operations, requiring extra work and additional time for drying.

5.234 OPERATIONAL PROCEDURES

The following outline describes the procedural steps of the original operation. The site is characterized by heavy clay soil, high summer temperatures, low humidity, and frequent breezes. Adjustments to the described schedule may be necessitated under different conditions and by the precautionary measures discussed below.

Step 1. Spread the discharged materials with the tandem drag immediately after discharge. Several passes may be required to achieve a thin, even distribution of materials and to assure that the large pieces have been sufficiently crushed.

Step 2. Allow the residual layer to dry for 48 hours.

Step 3. Incorporate the residuals into the soil with the discs. Several passes will be required for adequate mixing. The soil should be worked to a depth of six to eight inches.

Step 4. Allow the area to dry for 48 hours.

Step 5. Work the tandem drag over the area to crush any remaining large residual pieces and to level the soil. Look for "hot spots" (see Precautions below).

Step 6. Allow the area to dry for at least 48 hours.

Step 7. Disc the area several times to aerate the soil and facilitate final drying (Figure 5.16). Inspect for fly breeding (see Precautions below).

Step 8. Allow the area to dry for at least 48 hours.

Step 9. Work the drag over the area to level the soil for agricultural use.

When operating in sandy soils, it may be possible to omit the intermediate dragging (Step 5) and replace that step with an additional discing. Fewer passes will also expectedly be required with the discs to achieve adequate mixing and aeration in sandy soils.

5.235 PRECAUTIONS

The following precautionary measures must be observed to preclude or minimize nuisance conditions.

1. Uniformly-thin discharging of residuals from delivery trucks is mandatory for an efficient and successful operation. Piling *must* be avoided.

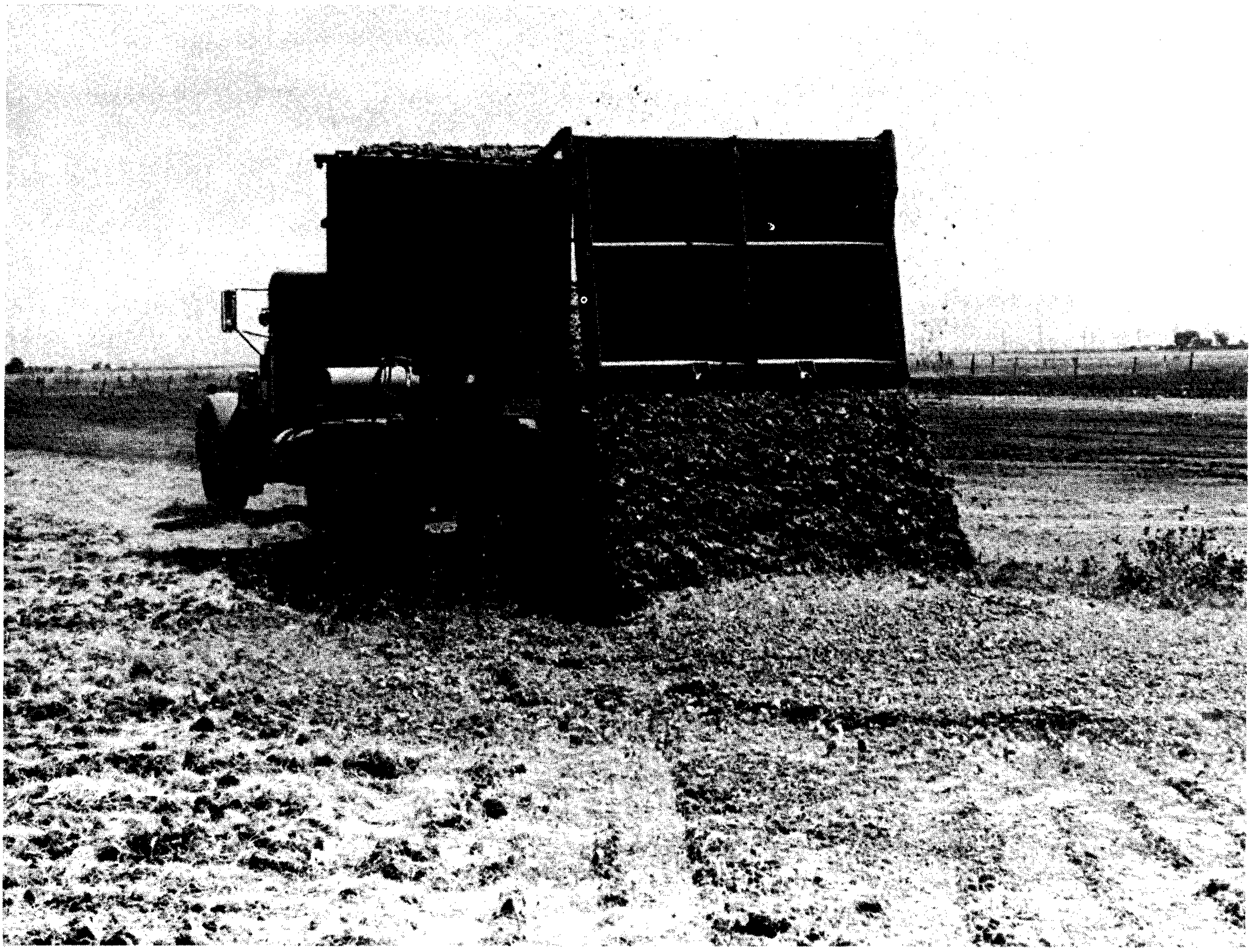

Figure 5.15. Discharging residuals evenly – an important step.

2. If piles are inadvertently deposited, the residuals must be spread immediately to prevent or minimize localized saturation of the soil.
3. "Hot spots" (areas which are excessively saturated due to piling or heavy application of residuals) must be constantly monitored. These areas become especially evident after the intermediate dragging (Step 5); "hot spots" can be identified by the darker coloration of moist soil. When these spots are observed, the area must be immediately disced, if necessary for several consecutive days, to accelerate drying and prevent fly breeding. When the area has dried sufficiently, the normal procedural steps may be resumed.
4. After each discing but before the next dragging, the area should be visually inspected for evidence of fly breeding. Spotchecks throughout the area should be made by turning the soil over with a shovel. If fly larvae are discovered in any area, that area must be immediately redisced as often as required to kill the larvae. Special attention must be given to areas where heavy applications of residuals have been made.
5. The procedural schedule has been designed to interrupt the normal four-day cycle for fly development. If fly breeding becomes evident, the discing frequency must be increased.
6. When operating the drag along the contours of sloping land, care must be exercised to assure that the drag does not dig into the soil at the lower end. This can be prevented by utilizing shorter drags. If the operation is conducted along the fall line of the slope, this will not be a necessary consideration.

5.236 FINAL SITE PREPARATION

To preclude the occurrence of problems during the first rains following an operating season, the residuals must be adequately stabilized. The operation must be continued until it is evident after discing that the residuals are sufficiently degraded or dried. Leveling the soil will aid surface drainage and minimize rainwater ponding which may contribute to later problems. Special attention must be given to preventing soil erosion of hilly sites during the off-season. It is recommended that such areas be dry planted with barley, wheat, or other similar crops immediately after the seasonal operation.

Figure 5.16. Final discing of the area facilitates degradation of food residuals.

5.24 Disposal of Seafood Residuals

Disposing of seafood processing residuals other than inert shells (oyster, clams, scallops) may pose serious difficulties. The highly putrescible nature of organic seafood wastes and their quickly evident inherent odors necessitate rapid handling in a manner that will not create aesthetically objectionable conditions. Disposal alternatives are unfortunately limited. Therefore, every effort should be made to seek an economical by-product outlet for these residuals (see Section 5.15).

5.241 LAND DISPOSAL OF SEAFOOD WASTES

Although seafood residuals readily enter the marine food chain and have enhanced the biota in the vicinity of previous discharges,[1] direct near-shore disposal of solid residuals in the 48 contiguous states has been prohibited. Barging of solids to designated deep ocean dumping sites is permitted but is prohibitively expensive for most processors. In locations where by-product recovery is not feasible the only alternative may be land disposal.

Seafood residuals alone are not readily amenable to land disposal. The unavoidable odors that are generated create aesthetically unacceptable conditions even in seemingly isolated locations. The high organic nitrogen content of these wastes seriously limits the application rate at spread sites, especially in pasturelands or where feed grasses are grown because high nitrate contents in forage and feed are toxic to livestock.

Seafood residuals are best disposed of at public sanitary landfill sites where the solids can be mixed with other refuse. Seafood wastes should be covered immediately with sufficient soil to prevent rodent, bird and insect activity and to suppress windborne dispersion of odors.

5.242 DISPOSAL AT ALASKAN FACILITIES

The environmental conditions at widely scattered plant locations within the State of Alaska vary between extremes, ranging from facilities isolated by hundreds of miles of ocean and unpopulated, inaccessible land to facilities located within the major cities. The different situations associated with plant locations have been recognized to a degree by the regulatory agencies, as reflected by slight differences in regulatory requirements depending on plant location.[1] Furthermore, the isolation of Alaskan facilities (including those located in population centers) from markets for by-products renders residuals

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[1] Stephens, J. S., Jr., *et al.* "Abundance, distribution, seasonality, and productivity of the fish populations in Los Angeles Harbor, 1972-73." *In* Soule, D. F., and M. Oguri (eds). *Marine Studies of San Pedro Bay, CA. Part IV.* Allan Hancock Foundation Publ. USC-SG-2-74:1-42. 1974.

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[1] Volume 40, Code of Federal Regulations, Part 408 – Effluent Guidelines and Standards for Canned and Preserved Seafood Processing Point Source Category.

utilization economically infeasible. Accordingly, seafood processors in Alaska are severely limited in disposal alternatives.

5.2421 Non-Remote Alaskan Plants

Seafood facilities located in Alaskan population or processing centers, including but not limited to Anchorage, Cordova, Juneau, Ketchikan, Kodiak, and Petersburg, must remove solid particles from wastewater prior to discharge. These screenings, together with other solid residuals, must be disposed of separately from liquid effluents. Where by-product facilities are infeasible, only two alternatives are available – the processor must use an existing landfill site or barge the solids and dispose of them in deep waters.

Both alternatives can pose problems for seafood processors. Environmentally acceptable landfill sites are limited in all areas of Alaska because of the mountainous terrain, shortage of cover soil and high annual rainfall and resulting runoff. Barging is expensive and subject to quickly changing weather conditions. Solids handling facilities must be provided with enough capacity to store the waste accumulated during bad weather when barges cannot operate. In all cases plants in these areas must exercise extreme care and exceptional foresight in the management of their solid residuals.

5.2422 Remote Alaska Plants

The effluent regulations promulgated by the Environmental Protection Agency for seafood processing facilities situated in remote Alaska locations permit these plants to grind and directly discharge solid residuals into receiving waters, provided that the particles do not exceed 0.5 inch in any dimension. This practice is environmentally sound since the discharged materials serve as food for marine organisms. By reducing the size of particles to at least 0.5 inch, the organic matter is more readily utilized by the biota and the inorganic matter more quickly degraded.

Several procedures may be employed to reduce solid residuals to the required size. The entire plant waste can be passed, either directly or from a sump, through an auger grinder with 0.5 inch grinder plate holes and then pumped to the receiving water. Other types of grinders, comminutors or mills may be used depending on the type of seafood solids to be handled. Alternatively, solids can be collected at the various waste generating locations throughout the plant using screens with 0.5 inch openings. These solids can then be passed through a grinder or mill which will reduce them to 0.5 inch or smaller. The ground waste can then be discharged with the liquid effluent.

In all cases careful consideration must be given to the location of the outfall. The discharge point must be situated where tides and currents will quickly disperse the solid particles, thereby minimizing the accumulation of settleable matter (sludge beds). Only by thorough and careful testing will the optimal location be determined for each site. This measure will assure that the discharge of solids into the marine environment will provide both immediate and long-term benefits.

SECTION 6

ADDENDA

by
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SECTION 6
ADDENDA

LIST OF TABLES

6.1

ENVIRONMENTAL LAWS AND REGULATIONS

GUIDE TO FEDERAL AND STATE LAWS AND REGULATIONS GOVERNING ENVIRONMENTAL QUALITY IN THE UNITED STATES

6.11 Water

Numerous laws have been enacted to protect the waters of the United States. The major statutes are listed in Table 6.1. Although most of these do not directly affect food processors generally, specific provisions in some may impinge upon operations in isolated situations. Details regarding laws and related regulations and whether or not they apply to an individual situation may be obtained from the Regional EPA offices listed in Section 6.21.

TABLE 6.1
STATUTES PERTAINING TO PROTECTION OF WATER QUALITY

Act	United States Code
The Refuse Act of 1899	33 U.S.C. 407
Fish and Wildlife Coordination Act	16 U.S.C. 661-666
Water Resources Planning Act	42 U.S.C. 1962
The National Environmental Policy Act	42 U.S.C. 4321, *et seq.*
Environmental Quality Improvement Act of 1970	42 U.S.C. 4371, *et seq.*
Federal Water Pollution Control Act	33 U.S.C. 1251, *et seq.*
Marine Protection, Research, and Sanctuaries Act of 1972	33 U.S.C. 1401, *et seq.*
Clean Water Act of 1977	(amended the FWPCA)

6.111 FEDERAL WATER POLLUTION CONTROL ACT

The Federal Water Pollution Control Act (FWPCA) was first passed in 1956 and subsequently amended by the Water Quality Act of 1965, by the Clean Water Restoration Act of 1966, and by the Water Quality Improvement Act of 1970. The Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500, replaced the previous language of the FWPCA entirely and has since been also further amended, most notably by the Clean Water Act of 1977, P.L. 95-217.

The provisions contained in the FWPCA and pertinent regulations that have been promulgated by the Administrator of the U.S. Environmental Protection Agency directly affect all industries. The major provisions which affect food processors are summarized in Table 6.2. Since the law and related regulations are subject to amendment and revision, interested persons are urged to contact either the Regional EPA office or the State regulatory agency.

Numerous regulations have been promulgated by the Administrator of the Environmental Protection Agency to enforce the provision of the FWPCA. These have been published in the *Federal Register* and copies are available from the Regional EPA offices.

6.112 STATE PROGRAMS

One of the major State programs dealing with water pollution control is the establishment of water quality standards as mandated by the Federal Water Pollution Control Act. The State standards generally contain variations of the basic standards which have been popularly referred to as the "Four Freedoms." These require that all waters within a State shall be:

1. Free from substances attributable to domestic or industrial waste or other controllable sources that will settle to form sludge or bottom deposits in amounts sufficient to interfere with any beneficial use of the water.
2. Free from floating debris, oil, grease, scum, and other

TABLE 6.2
PROVISIONS OF THE FWPCA

Subject	Section (33 USC §)	Provision
Construction grants	201-207 (1281-1287)	Provides Federal funds (up to 75%) for construction of publicly-owned treatment works; establishes procedures for payment, repayment; impose *industrial cost* recovery; appropriates funds and authorizes disbursement.
Areawide management	208 (1288)	Requires point sources to achieve effluent limitations reflecting the applicaagement plans; establishes parameters.
Basin plans	209 (1289)	Requires the preparation of plans under the Water Resources Planning Act for all basins in the United States.
Effluent limitations	301 (1311)	Requires point sources to achieve effluent limitations reflecting the application of various treatment technologies by specified dates; requires the Administrator to define those technologies; sets forth conditions for modifying the requirements.
Water quality related limits	302 (1312)	Provides for the establishment of more stringent effluent limitations where required to protect designated beneficial uses of water (water quality standards).
Water quality standards	303 (1313)	Requires each State to establish water quality standards for all navigable waters and their tributaries within its boundaries. (See State Programs, Section 6.112.)
Information and guidelines	304 (1314)	Requires the Administrator to publish various information, including identification of conventional pollutants, revision of effluent limitations, guidelines for controlling nonpoint sources, and guidelines for pretreatment of pollutants not susceptible to treatment by POTWs.
National standards of performance	306 (1316)	Requires the Administrator to publish a list of (industrial) categories of sources and promulgate regulations establishing performance standards for new sources within these categories; grants States to apply and enforce these standards.
Inspections, monitoring, and entry	308 (1318)	Authorizes the Administrator to require point source dischargers to report pertinent information; grants right of entry and access to pertinent records.
Federal enforcement	309 (1319)	Establishes Federal enforcement procedures; establishes liabilities for violations.
Thermal discharges	316 (1326)	Prohibits thermal discharges that will detrimentally affect aquatic biota.
Certification	401 (1341)	Requires the State or interstate water pollution control agency to certify that the applicant for a Federal license or permit to conduct any activity that may result in any discharge into navigable waters will be in compliance with the provisions of this Act.
National Pollutant Discharge Elimination System (NPDES)	402 (1342)	Establishes a permit system for the discharge of pollutants into navigable waters; requires those discharges to be in compliance with provisions of this Act. Grants authority to the States to administer the permit program. Requires the permits to state the conditions under which the discharges are allowed.
Ocean discharge criteria	402 (1343)	Requires the Administrator to promulgate guidelines for discharge of pollutants into ocean waters.
Citizen suits	505 (1365)	Provides for commencement of a civil suit by any citizen against violators of standards and limitations promulgated pursuant to the provisions of this Act.

floating materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to be unsightly, or in amounts sufficient to interfere with any beneficial use of the water.

3. Free from materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to produce taste or odor in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to change the existing color, turbidity or other conditions in the receiving stream to such a degree as to create a public nuisance, or in the amounts sufficient to interfere with any beneficial use of the water.
4. Free from toxic, corrosive, or other deleterious substances attributable to domestic or industrial waste or other controllable sources at levels or combinations sufficient to be toxic to human, animal, plant or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water.

In addition to these basic provisions, specific water quality criteria, or standards, have been established for all waters within each State. The standards consist of three major components: (1) designation of the beneficial uses which the water are to serve, (2) specification of narrative and numerical criteria to protect and enhance water quality, and (3) specification of a plan of implementation and enforcement, including treatment and control requirements for municipal, industrial, and other wastes discharged into or affecting interstate waters.

Designated beneficial uses include drinking water supply, recreation, fish and wildlife propagation, and industrial water supply. Each stream, or stretch of stream, has been classified by the State according to those beneficial uses determined to be applicable to local circumstances.

Numerical and narrative limits have been established on pollutants which can impair the quality of water required for each beneficial use. Specific requirements are based upon parameters (such as pH, temperature, dissolved oxygen, solids, bacteria) for which limits are varied depending upon the designated beneficial use of the receiving stream. Numerical criteria are used wherever it is reasonable to do so. However, narrative criteria are also employed in some cases, particularly with respect to aesthetic considerations. State standards contain selected specific requirements which are of particular interest to food processors. It is generally required that tests or analytical procedures which are used to determine compliance or non-compliance with water quality criteria be in accordance with methods set forth in the latest edition of *Standard Methods for the Examination of Water and Wastewater,* published by the American Public Health Association. Where other tests or analytical procedures are found to be more applicable and satisfactory, these are usually allowed upon acceptance by the appropriate regulatory agency.

Some waters have a higher quality than the minimum levels assigned for protection of water uses and the standards seek to protect this higher quality as much as possible in the fact of increasing social and economic development. Scientific knowledge about the exact water quality requirements for specific uses is limited. However, by preventing degradation of high quality waters the standards seek to assure optimum, not marginal, conditions to protect the uses associated with clean waters.

The adoption of an antidegradation policy is one of the requirements for full approval by the Administrator of the Environmental Protection Agency as provided for under the Federal Water Pollution Control Act. The following is a general statement on controlling degradation of high quality waters:

> Waters whose existing quality is better than the established standards as of the date on which such standards become effective will be maintained at that high quality unless it has been affirmatively demonstrated to the State that a change is justifiable as a result of necessary economic or social development and will not preclude present and anticipated use of such waters. Any indistrial, public or private project or development which would constitute a new source of pollution or an increased source of pollution to high quality waters will be required to provide the necessary degree of waste treatment to maintain high water quality.

Other State programs pertaining to wastewater treatment and discharge may include administration of the NPDES permit system, certification programs for operators of wastewater treatment facilities, and subsidies and tax incentive programs applicable to pollution abatement equipment. However, these programs have not been adopted by all States. The Regional EPA office maintains authority in those States that have chosen not to exercise enforcement of performance standards or administration of the NPDES program.

Questions regarding these matters, as well as effluent limitations, should be directed to the appropriate State regulatory agency listed in Section 6.221, or interstate commission listed in Section 6.23.

6.113 INTERSTATE PROGRAMS

Interstate programs based upon interstate agreements or compacts have been developed to facilitate solution of water quality problems involving two or more states. Under compacts formally entered into by the states with the approval of Congress, the signatory agencies have pledged cooperation and assistance in developing suitable policies and procedures for abating pollution originating in one state that detrimentally affects the interests of an adjacent or downstream state. Interstate commissions have been established under the compacts with representation from the signatory states, generally with federal participation, to develop and administer such cooperative programs.

The commissions are authorized to develop rules and regulations governing the conduct of such activities as authorized under the compacts. They have engaged in comprehensive planning for improving the quality of water resources in the river basins or compact areas, promulgating compatible water quality standards between the signatory states, developing schedules for implementation, including water quality monitoring, along with the technical, legal and economic studies involved. One important aspect of the various tasks performed is to provide the public with information on needs and measures to be carried out in the abatement of pollution.

To avoid unnecessary duplication and achieve maximum efficiency in conducting these interstate programs, it is usual practice to utilize to the fullest practical extent the cooperation of the state signatory agencies in enforcing regulations that are adopted by the commissions.

Further information can be obtained on current activities in the interstate programs of the commissions through participation in public meetings and through publications made available by requests sent to the interstate commissions listed in Section 6.23.

6.114 SAFE DRINKING WATER ACT

The Safe Drinking Water Act was first enacted by Congress on December 3, 1974, as Public Law 93-523 and amended on November 16, 1977, by Public Law 95-190. The statutes contained in this Act have been incorporated primarily into portions of Section 300, Title 42, the United States Code. This Act is intended to assure the provision of safe drinking water to the public and the protection of existing and future water supplies.

The Act directs the Administrator of the Environmental Protection Agency to establish National Primary Drinking Water Regulations for contaminants that exert adverse effects on the health of people, and National Secondary Drinking Water Regulations for contaminants that adversely affect public welfare. Each State has the option of assuming the primary responsibility for enforcing the provisions of the Act and pursuant regulations. Variances and exemptions may be granted by such States, provided there are no "unreasonable risks to health," whenever a public water system can demonstrate that it cannot reasonably comply with the regulations. However, the EPA Administrator retains final judgment.

The Act also directs the Administrator to develop regulations, where necessary, pertaining to underground injection of fluids. These regulations, designed to protect underground sources of drinking water, require permits for injection and establish monitoring and reporting procedures. Each State may be granted the primary enforcement responsibility; if any elect not to do so, the EPA retains that authority.

The Act also (1) grants the Administrator the authority to issue necessary orders whenever there is an "imminent and substantial danger to health," (2) establishes a procedure to assure that public water systems have access to chemicals necessary for treatment of drinking water, (3) authorizes Federal support of appropriate research and Federal grants for the development of State programs, (4) establishes a National Drinking Water Advisory Council, (5) provides a mechanism for the initiation of civil action by individuals, and (6) adds a new section, Bottled Drinking Water Standards, to the Federal Food, Drug and Cosmetic Act.

6.1141 National Drinking Water Regulations

The Administrator of the Environmental Protection Agency has promulgated primary drinking water regulations pursuant to the mandates of the Safe Drinking Water Act. These regulations appear in Title 40, Code of Federal Regulations, Part 141.

The regulations require that all piped drinking water provided to the public meet certain standards for specific constituents. The standards are expressed in terms of maximum permissible concentrations for inorganic and organic chemicals and as maximum "dose equivalents" for radioactive matter. Additionally, maximum contaminant levels for coliform bacteria have been set forth; the frequency of microbiological testing is specified and is based upon the population served. Acceptable analytical methods for all specified constituents are identified in the regulations. The contaminants for which maximum contaminant levels have been established are listed in Table 6.3.

TABLE 6.3
CONTAMINANTS LISTED IN THE NATIONAL PRIMARY DRINKING WATER REGULATIONS

Inorganic Chemicals	Organic Chemicals	Other
Arsenic	Chlorinated hydrocarbons:	Coliform bacteria
Barium	Endrin	
Cadmium	Lindane	Turbidity
Chromium	Methoxychlor	
Lead	Toxaphene	Radioactive materials:
Mercury		radium — 226
Nitrate (as N)	Chlorophenoxys:	radium — 228
Selenium		gross alpha particles
Silver	2,4 — D	
	2,4,5 — TP Silvex	man-made radionuclides beta particle and photon radioactivity

Since enforcement primacy is available to each state, the maximum contaminant levels may vary somewhat from those established by the Environmental Protection Agency. However, in no case may the state-established standards be more lenient than the federal standards.

6.12 Solid Waste

The Resource Conservation and Recovery Act of 1976, PL 94-580, was enacted "to provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials and for the safe disposal of discarded materials, and to regulate the management of hazardous waste." This Act completely replaced the previous language of the Solid Waste Disposal Act (42 U.S.C. 3251, *et seq.*).

The Act requires the establishment of an Office of Solid Waste within the Environmental Protection Agency. This Office is assigned the responsibility for carrying out the provisions of the Act. The major provisions pertaining to solid waste disposal are outlined in Table 6.4.

The various regulations promulgated pursuant to the Resource Conservation and Recovery Act are available from the Regional Offices of the Environmental Protection Agency. Since these may impinge upon the solid waste disposal practices of the food processing industry, processors should contact the nearest Regional Office listed in Section 6.21.

Of greater and direct significance, however, are the laws and regulations promulgated by state and local agencies pursuant to the mandates of this Act. These requirements may vary widely, not only between states, but within regions of each state. Food processors, especially those who conduct their own solid waste disposal operations, should contact the appropriate agency listed in Section 6.222 for copies of regulations pertaining to their area.

TABLE 6.4

MAJOR PROVISIONS OF THE RESOURCE CONSERVATION AND RECOVERY ACT OF 1976

Subject	Section	Provision
General Provisions		
Congressional findings	1002	Reports the findings of Congress regarding current and anticipated problems associated with solid wastes.
Solid waste management information and guidelines	1008	Requires the Administrator (EPA) to develop and publish guidelines for solid waste management, including levels of performance attainable by various solid waste management practices, minimum levels of performance required to protect the public and the environment, and the minimum criteria for determining unacceptable practices.
Hazardous Waste Management		
Identification and listing of hazardous waste	3001	Requires the Administrator to develop and promulgate criteria for identifying the characteristics of hazardous wastes and to list such wastes.
Generation of hazardous wastes	3002	Requires the promulgation of regulations establishing requirements for generators of hazardous wastes, including recordkeeping and reporting.
Transportation of hazardous wastes	3003	Requires the promulgation of regulations establishing standards to be met by transporters of hazardous wastes.
Treatment, storage, and disposal facilities	3004	Requires the promulgation of regulations establishing standards to be met by owners and operators of these facilities.
Permits	3005	Requires the owners and operators of the above facilities to have a permit.
State hazardous waste programs	3006	Requires EPA to develop guidelines for hazardous waste programs; requires states seeking authority to administer and enforce such programs to obtain EPA approval of their hazardous waste programs.
Inspections	3007	Provides designated EPA or state employees access and entry to hazardous wastes handling establishments, including records and sample collection; all reports to be made available to the public.
Federal enforcement	3008	Sets forth procedure for violations. establishes civil and criminal penalties.
State or Regional Solid Waste Plans		
Federal guidelines	4002	Requires the Administrator to publish guidelines for identifying areas with common solid waste management problems for the purpose of planning regional services; requires the promulgation of regulations containing guidelines for state solid waste management plans and specifies considerations which must be addressed.
Approval of plans	4003	Sets forth minimum requirements that must be met for approval of state or regional plans, including the closing of open dumps.
Sanitary landfills	4004	Requires the Administrator to promulgate regulations containing criteria for classifying sanitary landfills vs open dumps.
Open dumps	4005	Requires the Administrator to publish an inventory of open dumps; requires these dumps to be closed or upgraded.
State plan	4006	Sets forth the procedure for developing and implementing state plans, including identification of regions and responsible state and local agencies.
Approval of state plan	4007	Establishes the conditions which state plans must meet for approval by the Administrator; authorizes the Administrator to approve state applications for financial assistance for implementation of the plans.

6.2

REGULATORY AGENCIES

DIRECTORY OF FEDERAL, STATE, AND INTERSTATE AGENCIES CONCERNED WITH ENVIRONMENTAL PROTECTION

6.21 Environmental Protection Agency

Office of the Administrator
Waterside Mall
4th and M Streets, S.W.
Washington, D.C. 20460
(202) 755-2673

Regional Offices

Region I	Room 2203 John F. Kennedy Federal Building Boston, Mass. 02203 (617) 223-7210	CT, ME, MA NH, RI, VT
Region II	Room 908 26 Federal Plaza New York, N.Y. 10007 (212) 264-2525	NJ, NY, VI, PR
Region III	Curtis Building 6th and Walnut Streets Philadelphia, Pa. 19106 (215) 597-9801	DE, DC, MD PA, VA, WV
Region IV	1345 Courtland Street, N.E. Atlanta, Ga. 30308 (404) 526-5727	AL, FL, GA KY, MS, NC SC, TN
Region V	Federal Building 230 South Dearborn Chicago, Ill. 60604 (312) 353-5250	IL, IN, MI MN, OH, WI

Region VI	Suite 1100 1201 Elm Street Dallas, Tex. 75201 (214) 749-1962	AR, LA, NM OK, TX
Region VII	1735 Baltimore Street Kansas City, Mo. 64108 (816) 374-5493	IA, KS, MO, NB
Region VIII	Suite 900 1860 Lincoln Street Denver, Colo. 80203 (303) 837-3895	CO, MT, ND SD, UT, WY
Region IX	215 Fremont Street San Francisco, Calif. 94111 (415) 556-2320	AZ, CA, HI NV, GU Am Samoa
Region X	1200 6th Avenue Seattle, Wash. 98101 (206) 442-1220	AK, ID, OR, WA

6.22 State Regulatory Agencies

6.221 WATER PROGRAMS

Alabama:	Water Improvement Commission State Office Building Montgomery, Alabama 36104 (205) 269-7632
Alaska:	Division of Environmental Health Department of Health and Welfare Parish H Juneau, Alaska 99801 (907) 586-5371
Arizona:	Environmental Health Services Department of Health 4019 N. 33rd Ave., Hayden Plaza West Phoenix, Arizona 85017 (602) 271-5457
Arkansas:	Arkansas Pollution Control Commission 1100 Harrington Avenue Little Rock, Arkansas 77202 (501) 371-1701
California:	State Water Resources Control Board 1416 Ninth St., Room 1140 Sacramento, California 95814 (916) 445-3993
Colorado:	Water Pollution Control Division Colorado Department of Public Health 4210 East 11st Ave. Denver, Colorado 80220 (303) 388-6111
Connecticut:	State Water Resources Commission State Office Building, Room 225 Hartford, Connecticut 06115 (203) 566-2793
Delaware:	Division of Environmental Control Dept. of Natural Resources and Environmental Control P.O. Box 916 Dover, Delaware 19901 (302) 734-5711
D.C.:	D.C. Department of Public Health 1875 Connecticut Ave., N.W. Washington, D.C. 20009 (202) 629-3105
Florida:	Dept. of Air & Water Pollution Control Tallahassee Bank Bldg., Suite 300 Tallahassee, Florida 32301 (904) 224-9151
Georgia:	State Water Quality Control Board 47 Trinity Ave., S.W., Room 609 Atlanta, Georgia 30334 (404) 688-4033
Guam:	Water Pollution Control Commission Public Health and Social Services Government of Guam Agana, Guam 96910 424-143
Hawaii:	Environmental Health Section Hawaii Department of Health Honolulu, Hawaii 96801 (808) 507-711
Idaho:	Environmental Improvement Division Idaho Department of Health State House Boise, Idaho 83707 (208) 384-2390
Illinois:	Illinois Environment Protection Agency 535 West Jefferson St. Springfield, Illinois 62706 (217) 525-6580
Indiana:	Stream Pollution Control Board 1330 West Michigan St. Indianapolis, Indiana 46206 (317) 633-4420
Iowa:	State Department of Health Lucas State Office Building Des Moines, Iowa 50319 (515) 281-5011

Kansas:
Division of Environmental Health
Kansas State Department of Health
Topeka, Kansas 66612
(913) 296-3821

Kentucky:
Kentucky Water Pollution Control Commission
Frankfort, Kentucky 40601
(502) 564-3770

Louisiana:
Louisiana Stream Control Commission
P.O. Drawer Fc, University Station
Baton Rouge, Louisiana 70803
(504) 389-5309

Maine:
Environmental Improvement Commission
State House
Augusta, Maine 04330
(207) 289-2591

Maryland:
Environmental Health Services
State Department of Health and Mental Hygiene
2305 N. Charles St.
Baltimore, Maryland 21218
(301) 383-3010

Massachusetts:
Division of Water Pollution Control
Department of Natural Resources
Leverett Saltonstall Bldg.
Government Center
Boston, Massachusetts 02202
(617) 727-3855

Michigan:
Michigan Water Resources Commission
Steven T. Mason Bldg., Station A
Lansing, Michigan 48926
(517) 373-3560

Minnesota:
Minnesota Pollution Control Agency
717 Delaware Street, S.E.
Minneapolis, Minnesota 55440
(612) 378-1320

Mississippi:
Mississippi Air & Water Pollution Control Commission
P.O. Box 827
Jackson, Mississippi 39205
(601) 354-6783

Missouri:
Missouri Water Pollution Board
P.O. Box 154
Jefferson City, Missouri 65101
(314) 635-9117

Montana:
Montana Water Pollution Control Council
Division of Environmental Sanitation
Montana Department of Health
Helena, Montana 59601
(406) 449-2406

Nebraska:
Nebraska Water Pollution Control Council
State Department of Health
State House Station, Box 94757
Lincoln, Nebraska 68509
(402) 473-1484

Nevada:
Department of Health, Welfare & Rehabilitation
Nye Bldg., 201 S. Fall St.
Carson City, Nevada 89701
(702) 882-7458

New Hampshire:
Water Supply & Pollution Control Commission
105 Loudon Road, Prescott Park
Concord, New Hampshire 03301
(603) 271-3502

New Jersey:
Department of Environmental Protection
P.O. Box 1390
Trenton, New Jersey 08625
(609) 292-5383

New Mexico:
New Mexico Water Quality Control Commission
New Mexico Health & Social Services Dept.
P.O. Box 2348
Santa Fe, New Mexico 84501
(505) 827-2371

New York:
Department of Environmental Conservation
Albany, New York 12201
(518) 474-2934

North Carolina:
Department of Water & Air Resources
P.O. Box 9392
Raleigh, North Carolina 27611
(919) 829-3006

North Dakota:
Environmental Health & Engineering Service
North Dakota State Department of Health
Bismarck, North Dakota 58501
(701) 224-2371

Ohio:
Water Pollution Control Board
State Department of Health
P.O. Box 118
Columbus, Ohio 43216
(614) 469-2253

Oklahoma:
Environmental Health Services
State Department of Health
3400 North Eastern Ave.
Oklahoma City, Oklahoma 73105
(405) 427-2955

Oregon:
Department of Environmental Quality
P.O. Box 231
Portland, Oregon 97207
(503) 226-2161

Pennsylvania:
Bureau of Sanitary Engineering
State Department of Health
P.O. Box 90
Harrisburg, Pennsylvania 17120
(717) 787-2666

Puerto Rico:
Institute of Health
Box 1730
Hatorey, Puerto Rico 00191
(809) 767-2014

Rhode Island:
Rhode Island Department of Health
40 Fountain Street
Providence, Rhode Island 02903
(401) 521-7100

South Carolina:
South Carolina Pollution Control Authority
V. Marian Sims Bldg.
Columbia, South Carolina 29201
(803) 758-5631

South Dakota:
Division of Sanitary Engineering
South Dakota State Department of Health
Pierre, South Dakota 57501
(605) 224-3351

Tennessee:
Tennessee Stream Pollution Control Board
Cordell Hull Bldg., Room 621
5th Avenue, North
Nashville, Tennessee 37219
(615) 741-2275

Texas:
Texas Water Quality Board
1108 Lavaca St.
Austin, Texas 78701
(512) 475-2651

Utah:
Water Pollution Control Committee
Div. of Health, Dept. of Social Services
84 Medical Drive
Salt Lake City, Utah 84113
(801) 328-6121

Vermont:
Department of Water Resources
State Office Bldg.
Montpelier, Vermont 05602
(802) 223-2311

Virginia:
State Water Control Board
P.O. Box 11143
Richmond, Virginia 23230
(703) 770-2241

Virgin Islands:
Virgin Islands Department of Health
Charlotte Amalie
St. Thomas, Virgin Islands 00802
(809) 774-1321

Washington:
Washington Department of Ecology
P.O. Box 829
Olympia, Washington 98501
(206) 753-6877

West Virginia:
Division of Water Resources
Department of Natural Resources
1201 Greenbrier St.
Charleston, West Virginia 53701
(304) 348-2107

Wisconsin:
Division of Environmental Protection
Wisconsin Department of Natural Resources
P.O. Box 450
Madison, Wisconsin 53701
(608) 226-2747

Wyoming:
Sanitary Engineering Services
Wyoming Department of Health and Social Services
Division of Health and Medical Services
State Office Bldg.
Cheyenne, Wyoming 82001
(307) 777-7513

6.222 SOLID WASTE PROGRAMS

Alabama
Department of Public Health
Environmental Health Administration
Division of Solid Waste
State Office Building
Montgomery, Ala. 36130
(205) 832-6728

Alaska
Department of Environmental Conservation
Terrestrial Programs Division
Solid Waste Management Section
Pouch O
Juneau, Alaska 99811
(907) 586-6721

Arizona
Department of Health Services
Environmental Health Services, Solid Waste Section, Sanitation Division
1740 West Adams Street
Phoenix, Ariz. 85007
(602) 271-4641

Arkansas
Department of Pollution Control and Ecology
8001 National Drive
Little Rock, Ark. 72209
(501) 371-1701

California
Solid Waste Management Board
1709 11th Street
Sacramento, Calif. 95814
(916) 322-3330

Colorado
Department of Health
Division of Radiological and Hazardous Waste
4210 East 11th Avenue
Denver, Colo. 80220
(303) 388-6111

Connecticut
Department of Environmental Protection
Division of Environmental Quality, Solid Waste Management Programs
State Office Building
Hartford, Conn. 06115
(203) 566-5524

Delaware
Department of Natural Resources and Environmental Control
Division of Environmental Control, Solid Waste Mgmt.
Capital Complex
Dover, Del. 19901
(302) 678-4781

D.C.
Solid Waste Administration
415 12th Street, N.W.
Washington, D.C. 20004
(202) 629-4581

Florida
Department of Environmental Regulation Commission
Solid Waste Management Program
2562 Executive Center Circle East
Tallahassee, Fla. 32301
(904) 488-7937

Georgia
Department of Natural Resources
Environmental Protection Division, Solid Waste Management Branch
270 Washington Street, S.W. Room 822
Atlanta, Ga. 30334
(404) 656-3550

Hawaii
Department of Health
Environmental Health Division
P.O. Box 3378
Honolulu, Hawaii 96801
(808) 548-2811

Idaho
Department of Health and Welfare
Division of Environment
Bureau of Solid Waste Management
Statehouse
Boise, Idaho 83720
(208) 384-2390

Illinois
Environmental Protection Agency
Division of Water Pollution Control
2200 Churchill Road
Springfield, Ill. 62706
(217) 782-5562

Indiana
Board of Health
General Sanitation Section
1330 West Michigan Street
Indianapolis, Ind. 46206
(317) 633-6400

Iowa
Department of Environmental Quality
Solid Waste Management Division
3920 Delaware Avenue
P.O. Box 3326
Des Moines, Iowa 50316
(515) 265-8134

Kansas
Department of Health and Environment
Division of Environment
Bureau of Environmental Sanitation, Solid Waste Management
Forbes AFB Building No. 740
Topeka, Kan. 66620
(913) 296-3821

Kentucky
Department of Natural Resources and Environmental Protection
Division of Solid Waste
275 East Main Street
Frankfort, Ky. 40601
(502) 564-6717

Louisiana
Department of Health
Bureau of Environmental Services
P.O. Box 60630
New Orleans, La. 70160
(504) 527-5111

Maine
Department of Environmental Protection
Division of Solid Waste Management
Vickery-Hill
Augusta, Me. 04330
(207) 289-2963

Maryland
Department of Health and Mental Hygiene, Environmental Health Administration
Division of Solid Waste Control
P.O. Box 13387
Baltimore, Md. 21203
(301) 383-2771

Massachusetts
Department of Environmental Quality Engineering
Bureau of Community Sanitation
100 Nashua Street, Room 526
Boston, Mass. 02114
(617) 727-4293

Michigan
Department of Natural Resources
Environmental Protection Branch, Solid Waste Management Division
P.O. Box 30028
Lansing, Mich. 48909
(517) 373-1214

Minnesota
Pollution Control Agency
Solid Waste Division
1935 West County Road B2
Roseville, Minn. 55113
(612) 296-7283

Mississippi
Board of Health
Bureau of Environmental Health
Division of Solid Waste Management and Vector Control
P.O. Box 1700
Jackson, Miss. 39205
(601) 354-6616

Missouri
Department of Natural Resources
Division of Environmental Quality
Solid Waste Section
P.O. Box 1368
Jefferson City, Mo. 65101
(314) 751-3241

Montana
Department of Health and Environmental Sciences
Division of Environmental Sciences
Solid Waste Bureau
1424 9th Avenue
Helena, Mont. 59601
(406) 449-2821

Nebraska
Department of Environmental Control
Solid Waste Pollution Control Division
P.O. Box 94653
1424 P Street
Lincoln, Neb. 68509
(402) 471-2186

Nevada
Bureau of Environmental Health
Solid Waste Office
1209 Johnson Street
Carson City, Nev. 89701
(702) 885-4670

New Hampshire
Department of Health and Welfare
Division of Health Services
Consumer Protection-Public Health
Solid Waste Management Office
State Laboratory Building
Hazen Drive
Concord, N.H. 03301
(603) 271-2605

New Jersey
Department of Environmental Protection
Solid Waste Administration
32 E. Hanover Street
Trenton, N.J. 08625
(609) 292-2994

New Mexico
Environmental Improvement Agency
General Sanitation Division, Solid Waste Management Section
P.O. Box 2348
Santa Fe, N.M. 87503
(505) 827-2307

New York
Department of Environmental Conservation
Division of Solid Waste Management
50 Wolf Road
Albany, N.Y. 12233
(518) 457-5400

North Carolina
Department of Human Resources
Division of Health Services
Sanitary Engineering Section
Solid Waste And Vector Control Branch
P.O. Box 2091
Raleigh, N.C. 27602
(919) 829-2178

North Dakota
Department of Health
Division of Water Supply and Pollution Control
1200 Missouri Avenue
Bismarck, N.D. 58505
(701) 224-2386

Ohio
Environmental Protection Agency
316 E. Broad Street
P.O. Box 1049
Columbus, Ohio 43216
(614) 466-8505

Oklahoma
Department of Health
Environmental Health Services
Sanitation Service
Solid Waste Management Division
N.E. 10th and Stonewall
Oklahoma City, Okla. 73105
(405) 271-5601

Oregon
Department of Environmental Quality
Solid Waste Division
1234 S.W. Morrison
Portland, Ore. 97205
(503) 229-5327

Pennsylvania
Department of Environmental Resources
Bureau of Land Protection
Division of Solid Waste Management
P.O. Box 2063
Harrisburg, Penna. 17120
(717) 787-1323

Rhode Island
Department of Health
Division of Solid Waste Management
Health Building
Davis Street
Providence, R. I. 02908
(401) 277-2808

South Carolina
Department of Health and Environmental Control
Bureau of Special Environmental Programs
Solid Waste Management Division
2600 Bull Street, J. Marion Sims Bldg.
Columbia, S.C. 29201
(803) 758-5500

South Dakota
Department of Environmental Protection
Solid Waste and Pesticides Program
Capitol Building, Number 2
Pierre, S.D. 57501
(605) 224-3259

Tennessee
Department of Public Health
Bureau of Environmental Health Services
Sanitation and Solid Waste Management Division
320 Capitol Hill Building
Nashville, Tenn. 37219
(615) 741-2951

Texas
Water Quality Board (for industrial solid waste)
P.O. Box 13246
Capitol Station
Austin, Tex. 78756
(512) 475-2188

Utah
Division of Health
Environmental Health Services Branch
Bureau of Solid Waste Management
44 Medical Drive
Salt Lake City, Utah 84113
(801) 328-6163

Vermont
Agency of Environmental Conservation
Environmental Engineering Division
Air and Solid Waste Programs
P.O. Box 489
Montpelier, Vt. 05602
(802) 282-3357

Virginia
Health Department
Bureau of Solid Waste and Vector Control
Room 209
401 A Colley Avenue
Norfolk, Va. 23507
(804) 627-4511

Washington
Department of Ecology
Office of Land programs
Solid Waste Office
Olympia, Wash. 98504
(206) 753-2813

West Virginia
Department of Health
Environmental Health Service
Bureau of Solid Waste Disposal
1800 Washington Street, Room 554
Charleston, W.Va. 25305
(304) 348-2987

Wisconsin
Department of Natural Resources
Division of Environmental Standards
Bureau of Air Pollution Control and Solid Waste Management
Solid Waste Management Section
P.O. Box 7921
Madison, Wis. 58707
(608) 266-0158

Wyoming
Department of Environmental Quality
Solid Waste Management Program
Hathaway Building
Cheyenne, Wyo. 82002
(307) 777-7752

6.23 Interstate Commissions

Interstate commissions largely concerned with water quality regulatory measures that have been established in past years under compacts, and their respective signatory states, are the following:

Bi-State Development Agency
Suite 619 Paul Brown Bldg.
St. Louis, Missouri 63101
Illinois
Missouri

Hudson River Valley Commission
30 Rockefeller Plaza
New York, New York 10020
Connecticut
New Jersey
New York

Ohio River Valley Water Sanitation Commission
414 Walnut Street
Cincinnati, Ohio 45202
Illinois
Indiana
Kentucky
New York
Ohio
Pennsylvania
Virginia
West Virginia

Delaware River Basin Commission
25 Scotch Road, P.O. Box 360
Trenton, New Jersey 08603
Delaware
New Jersey
New York
Pennsylvania

Klamath River Compact Commission
P.O. Box 388
Sacramento, California 95802
California
Oregon

Tennessee River Basin Water Pollution Control Commission
Central Services Building
Nashville, Tennessee 37219
Kentucky
Mississippi
Tennessee

Interstate Commission on the Potomac River Basin
1025 Vermont Avenue, N.W.
Washington, D.C. 20005
District of Columbia
Maryland
Pennsylvania
Virginia
West Virginia

New England Interstate Water Pollution Control Commission
73 Tremont Street
Boston, Massachusetts 02108
Connecticut
Maine
Massachusetts
New Hampshire
New York
Rhode Island
Vermont

6.3

GLOSSARY OF TERMS

DEFINITION OF TERMS USED IN WATER AND WASTE MANAGEMENT

ABS – Customary abbreviation of sodium alkyl benzene sulfonate. See *alkyl benzene sulfonate.*

absorption – The taking up of one substance into the body of another.

accelerated depreciation – In pollution abatement, an arrangement whereby, as an incentive to industry to install pollution abatement equipment, a company is allowed to deduct from its taxable income the entire cost of such equipment over a shorter period of time (perhaps only one to three years) than in the case of other types of capital investment.

acid – (1) A substance that tends to lose a proton. (2) A substance that dissolves in water with the formation of hydrogen ions. (3) A substance containing hydrogen which may be replaced by metals to form salts.

acidic – The condition of water, wastewater, or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

acidity – The quantitative capacity of aqueous solutions to react with hydroxyl ions. It is measured by titration with a standard solution of a base to a specific end point. Usually expressed as milligrams per liter of calcium carbonate.

acre-foot – (1) A volume of water 1 ft deep and 1 acre in area, or 43,560 cu. ft. (2) A 43,560-cu. ft. volume of trickling filter medium.

activated carbon – Carbon particles usually obtained by carbonization of cellulosic material in the absence of air and possessing a high adsorptive capacity.

activated sludge – Sludge floc produced in raw or settled wastewater by the growth of zoogleal bacteria and other organisms in the presence of dissolved oxygen and accumulated in sufficient concentration by returning floc previously formed.

activated sludge process – A biological wastewater treatment process in which a mixture of wastewater and sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and wasted or returned to the process as needed. The treated wastewater overflows the weir of the settling tank in which separation from the sludge takes place.

adsorption – A taking up of gases or liquids by the surface of solids or liquids with which they are in contact.

advanced waste treatment – A term including any treatment process applied for renovation of wastewater that goes beyond the usual 90-99% oxygen demand and organic solids removal of secondary treatment. May include nitrogen, phosphorous, other minerals, taste, odor, color, and turbidity removal by a variety of conventional and special processes as required to renovate wastewater for intended reuse.

aerated pond – A natural or artificial wastewater treatment pond in which mechanical or diffused-air aeration is used to supplement the oxygen supply. See *oxidation pond.*

aeration – The bringing about of intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, (c) agitating the liquid to promote surface absorption of air.

aeration period – (1) The theoretical time, usually expressed in hours, during which mixed liquor is subjected to aeration in an aeration tank while undergoing activated sludge treatment. It is equal to the volume of the tank divided by the volumetric rate of flow of the wastewater and return sludge. (2) The theoretical time during which water is subjected to aeration.

aerator – A device that promotes aeration.

aerobic – (1) A condition characterized by an excess of dissolved oxygen in the aquatic environment. (2) Living or taking place only in the presence of molecular oxygen.

aerobic bacteria – Bacteria which require the presence of free (dissolved or molecular) oxygen for their metabolic processes. Oxygen in chemical combination will not support aerobic organisms.

agglomeration – An action by which small particles gather into larger particles that are more readily separated from the liquid by sedimentation or other means. May be the result of biological, chemical or physical factors.

algae – Primitive plants, one- or many-celled, usually aquatic, and capable of elaborating their foodstuffs by photosynthesis. Generally considered as the source of food for other organisms.

algicide – A chemical (such as copper sulfate) used to kill or inhibit the growth of algae.

alkali – Any of certain soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical processes such as water or wastewater treatment.

alkaline – The condition of water, wastewater, or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

alkalinity – The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate. Natural waters are generally neutral or slightly alkaline. The alkalinity of water may range from a few milligrams per liter to several hundred. Domestic sewage is usually slightly more alkaline than the water from which it is derived.

alkyl benzene sulfonate – Technically, a broad class of anionic surface-active materials of the form $R{\cdot}C_6H_4SO_3Na$, of which the alkyl portion "R" can be of various chain lengths and molecular configurations. In common usage, however, because of the large volume used, ABS has become identified with the specific commercial material derived from polypropylene, with an average alkyl chain length of approximately 12 carbon atoms. ABS has been widely used in synthetic detergents, but has largely been replaced with linear alkylate sulfonate (LAS).

alum – A chemical substance (usually potassium aluminum sulfate), gelatinous when wet, used in water-treatment plants for settling out small particles of foreign matter.

amortization – (1) Gradual reduction, redemption, or liquidation of the balance of an account according to a specified schedule of times and amounts. (2) Provision for the extinguishment of a debt by means of a sinking fund.

anaerobic – (1) A condition in which dissolved oxygen is undetectable in the aquatic environment. Usually characterized by formation of reduced sulfur compounds such as sulfides in a putrefaction activity. (2) Living or taking place in the absence of molecular oxygen.

anaerobic bacteria – Bacteria that do not require the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered or completely blocked by the presence of dissolved oxygen and in some cases by the presence of highly oxidized substances such as sodium nitrates, nitrites, and perhaps sulfates. Facultative anaerobes can be active in the presence of dissolved oxygen but do not require its presence.

anaerobic contact process – An anaerobic waste treatment process in which the microorganisms responsible for waste stabilization are removed from the treated effluent stream by sedimentation or other means held in or returned to the process to enhance the rate of treatment.

anaerobic digestion – The degradation of organic matter brought about through the action of microorganisms in the absence of elemental oxygen.

anion – A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of electrical potential.

aquatic growth – The aggregate of passively floating or drifting or attached organisms in a body of water; plankton.

aquifer – A porous layer of rock that carries a usable supply of water. Gravel, sand, sandstone, and limestone are the best water carriers; clay, shale, and crystalline rocks are poor water carriers.

assessment – A legal financial obligation of the property owner in an irrigation, water, drainage or sanitary district. Created for the purpose of financing the construction and operation of facilities required to protect and enhance public benefit within the district.

assimilative capacity – The capacity of a natural body of water to receive: (a) wastewaters, without deleterious effects; (b) toxic materials, without damage to aquatic life or humans who consume the water; (c) BOD, within prescribed dissolved oxygen limits.

available chlorine– A measure of the total oxidizing power of chlorinated lime and hypochlorites.

backwashing – The operation of cleaning a filter by reversing the flow of liquid through it and washing out matter previously captured in it. Filters would include true filters such as sand and diatomaceous-earth types but not other treatment units such as trickling filters.

bacteria – A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll. Bacteria usually appear as spheroid, rod-like, or curved entities, but occasionally appear as sheets, chains, or branched filaments. Bacteria are usually regarded as plants. Also see following terms modifying bacteria: *aerobic, anaerobic, coliform, Escherichia coli, facultative, iron, pathogenic, saprophytic, sulfur.*

bacterial count – A measure of the concentration of bacteria.

bar rack (screen) – A screen composed of parallel bars, either vertical or inclined, placed in a waterway to catch floating debris, and from which the screenings may be raked.

base – A compound which dissociates in aqueous solution to yield hydroxyl ions.

base flow – That part of the stream discharge that is not attributable to direct runoff from precipitation or melting snow; it is usually sustained by water draining from natural storage in groundwater bodies, lakes, or swamps.

belt screen – An endless band of wire mesh bars plates, or other screening medium which passes around upper and lower rollers as guides and from which the material caught on the screen is usually removed by gravity, brushes, or other means. Also called band screen.

benefit-cost analysis – Economic analysis of a resource development project, taking into account both known and projected factors with a view to discovering the relative efficiency of the project.

bioassay – (1) An assay method using a change in biological activity as a qualitative or quantitative means of analyzing a material's response to biological treatment. (2) A method of determining toxic effects of industrial wastes and other wastewaters by using viable organisms or live fish as test organisms.

biochemical – (1) Resulting from biologic growth or activity, and measured by or expressed in terms of the ensuing chemical change. (2) Pertaining to the chemistry of plant and animal life.

biochemical oxygen demand – A standard test used in assessing wastewater strength. See *BOD*.

biodegradable detergent – One that decomposes quickly as a result of the action of organisms, eliminating foam in wastewater. Biodegradable is defined as having at least 90 percent surfactant reduction, or as having surfactant concentration no higher than 0.5 mg/l.

biodegradation – The destruction or mineralization of either natural or synthetic organic materials by the microorganisms populating soils, natural bodies of water, or wastewater treatment systems.

biological filtration – The process of passing a liquid through the medium of a biological filter, thus permitting contact with attached zoogleal films that adsorb and absorb fine suspended, colloidal, and dissolved solids and release end products of biochemical action.

biological oxidation – The process whereby living organisms in the presence of oxygen convert the organic matter contained in wastewater into a more stable or a mineral form.

biological process – (1) The process by which the life activities of bacteria and other microorganisms, in the search for food, break down complex organic materials into simple, more stable substances. Self-purification of polluted streams, sludge digestion, and all the so-called secondary wastewater treatments result from this process. (2) Process involving living organisms and their life activities. Also called biochemical process.

biological slime – The gelatinous film of zoogleal growths covering the medium or spanning the interstices of a biological bed. Also called microbial film.

biological wastewater treatment – Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Intermittent sand filters, contact beds, trickling filters, and activated sludge processes are examples.

biota – Animal and plant life, or fauna and flora, of a stream or other water body.

bloom – The excessive growth of algae in a body of water due to an oversupply of dissolved nutrients; it may impart a disagreeable odor to the water, cause fish to die, and impair the use of the water for drinking or recreation. (See *eutrophication*).

BOD – (1) Abbreviation for biochemical oxygen demand. The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater strength.

BOD load – The BOD content, usually expressed in pounds per unit of time, of wastewater passing into a waste treatment system or to a body of water.

BOD:N:P ratio – The ratio, based upon analysis of wastewater passing into a waste treatment system , of the BOD to total nitrogen to total phosphorus contained in the waste stream. To assure a nutrient balance within a biological treatment system, a ratio of 100:5:1 is generally recommended.

brackish water – Water having a mineral content in the general range between fresh water and seawater. Water containing from 1,000 to 10,000 mg/l of dissolved solids.

breakpoint chlorination – Addition of chlorine to water or wastewater until the chlorine demand has been satisfied and further additions result in a residual that is directly proportional to the amount added beyond the breakpoint.

buffer action – The action exhibited by certain chemicals that resist a change in the effective acidity or hydrated H+ ion content of a solution. In surface water the primary buffer action is related to carbon dioxide, bicarbonate and carbonate equilibria.

bulkhead – (1) A structure of wood, stone, or concrete along the shore of a water body to arrest wave action or along a steep embankment to control erosion. (2) A permanent or movable wall closely fitting into and across a waterway and intended to hold back earth or water pressures.

bulking sludge – An activated sludge that settles poorly because of a floc of low density.

carbohydrates – Naturally occuring compounds consisting of carbon, hydrogen and oxygen that are considered as energy foods and precursors of proteins and fats.

catch basin – A cistern situated at a point where waste water discharges into a sewer, to catch and retain matter that would not pass readily through the sewer; a reservoir or well into which surface water may drain.

cation – The ion in an electrolyte which carries the positive charge and which migrates toward the cathode under the influence of a potential difference.

centrifuge – A mechanical device in which centrifugal force is used to separate solids from liquids and/or to separate liquids of different densities.

cfs – Cubic feet per second; a measure of discharge – the amount of water passing a given point.

chelating agent – A chemical or complex which causes an ion, usually a metal, to be joined in the same molecule by both ordinary and coordinate valence forces. Such linkages result in the formation of one or more heterocyclic rings in which the metal atom is part of the ring. Commercially available chelating agents may be used to remove traces of metal ions in industrial and biological processes. See *sequestering agent.*

chelation – The formation of an inner complex compound soluble in water in which the same molecule is attached to a central atom at two different points, forming a ring structure.

chemical oxidation – Oxidation of organic substances without benefit of living organisms. Examples are by thermal combustion or by oxidizing agents such as chlorine.

chemical oxygen demand – (COD) A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

chloramines – Compounds of organic or inorganic nitrogen and chlorine.

chlorination – The application of chlorine to water or wastewater for the purposes of disinfection, oxidation, odor control or other effects.

chlorination chamber – See *chlorine-contact chamber.*

chlorine – A greenish yellow gaseous element having strong disinfecting and oxidizing properties in water solution. It is commercially available as compressed gas, liquid or in combined form as a powder. It is highly toxic and irritating to skin, eyes, and lungs in significant concentration.

chlorine-contact chamber – In a waste-treatment plant, a chamber in which effluent is disinfected with chlorine before it is discharged to the receiving waters.

chlorine demand – The difference between applied chlorine and residual available chlorine in aqueous media under specified conditions and contact time. Chorine demand varies with dosage, time, temperature and nature of the water impurities.

chlorine test – Refers to one of two methods commonly employed to determine the concentration of available chlorine. The test methods are (a) colorimetric using the dye, orthotolidine, and (b) amperometric using phenyl arsene oxide titrant.

clarification – Any process or combination of processes the primary purpose of which is to reduce the concentration of suspended matter in a liquid.

clarified wastewater – Wastewater from which most of the setteable solids have been removed by sedimentation. Also called settled wastewater.

clarifier – A basin or tank serving as an enlargement of a channel to permit separation of floatable or settleable materials from the clarified water (a sedimentation basin).

C/N ratio – The weight ratio of carbon to nitrogen.

coagulant – A compound responsible for coagulation; a floc-forming agent.

coagulation – The process of modifying chemical, physical or biological conditions to cause flocculation or agglomeration of particulates.

COD – Symbol for *chemical oxygen demand.*

coliform group – A group of bacteria predominantly inhabiting the intestines of man or animal, but also occasionally found elsewhere. It includes all aerobic and facultative anaerobic, Gram-negative, non-spore forming bacilli that ferment lactose with production of gas. Also included are all bacteria that produce a dark, purplish-green colony with metallic sheen by the membrane-filter technique used for coliform identification. The two groups are not always identical, but they are generally of equal sanitary significance. Their presence in water is presumptive evidence of contamination by fecal material.

coliform count, coliform index – An index of the purity of water based on a count of its coliform bacteria.

collecting sewer, collecting system – (1) A system of conduits (canals, ditches, pipelines, tunnels), used to carry a water supply obtained from several different sources, such as different streams, to a common point. This point may be a reservoir, the intake of the main conduit or aqueduct, or the intake of the distributing system. (2) See *sewer system.*

colloids – (1) Finely divided solids which will not settle but may be removed by coagulation or biochemical action or membrane filtration; they are intermediate between true solutions and suspensions. (2) In soil physics, discrete mineral particles less than two microns in diameter. (3) Finely divided dispersions of one material, called the dispersed phase, with another, called the dispersion medium. (4) In general, particles of colloidal dimensions are approximately 10 A to 1μ in size. Colloidal particles are distinguished from ordinary molecules by their inability to diffuse through membranes that allow ordinary molecules and ions to pass freely.

combined available chlorine – The concentration of chlorine which is combined with ammonia as chloramine or as other chloro derivatives, yet is still available to oxidize organic matter.

combined sewer – A sewer designed to carry wastewaters and storm waters in the same channel.

comminution – (1) The act of cutting and screening materials contained in wastewaters. (2) To reduce the size of fibrous or amorphous materials.

comminutor – In a waste-treatment plant, a device that grinds solids to make them easier to treat.

common sewer – A sewer in which all owners of abutting properties have equal rights.

composite wastewater sample – A combination of individual samples of water or wastewater taken at selected intervals, generally hourly for some specified period, to minimize the effect of the variability of the individual sample. Individual samples may have equal volume or may be roughly proportioned to the flow at time of sampling.

composting – Composting is the aerobic, thermophilic decomposition of organic wastes to a relatively stable humus. The resulting humus may contain up to 25 percent living organisms and is subject to further, slower decay but should be sufficiently stable not to reheat or cause odor or fly problems. In composting, mixing and aeration are provided to maintain aerobic conditions and permit adequate heat development. The decomposition is done by aerobic organisms, primarily bacteria, actinomycetes and fungi.

conservation – Managed human ecology whereby man achieves an optimum relationship with the resources in his natural environment. It embraces both preservation and wise use of natural resources.

consumptive use of water – Water use resulting in a large proportion of loss to the atmosphere by evapotranspiration (as in irrigation), or by combination with a manufactured product.

contact stabilization process – A modification of the activated sludge process in which raw wastewater is aerated with a high concentration of activated sludge for a short period, usually less than 60 min, to obtain BOD removal by absorption. The solids are subsequently removed by sedimentation and transferred to a stabilization tank where aeration is continued further to oxidize and condition them before their reintroduction to the raw wastewater flow.

contamination – A general term referring to the introduction of materials into water that makes the water less desirable for its intended use. Also, introduction of undesired substance in air, solutions, or other defined media (chemical or biological).

conventional wastewater treatment – Wastewater treatment including screening, sedimentation, coagulation, rapid sand filtration, and disinfection with chlorine.

cooling tower – A hollow, vertical structure with internal baffles to break up falling water so that it is cooled by upward-flowing air and by evaporation of water.

cooling water – Water used for cooling in an industrial or manufacturing process; since its temperature after use is normally higher than that of the lake or stream into which it is discharged, it may constitute a source of thermal pollution.

cooling water load – Energy in the form of heat dissipated by cooling water.

cost-benefit analysis – See *benefit-cost analysis.*

cross connection – In plumbing, a physical connection between two different water systems, such as between potable and polluted water lines.

cubic foot per second (C.F.S.) – A unit of measure of the rate of liquid flow past a given point equal to one cubic foot in one second. Previously also called second-foot.

dead-well – A shaft or well driven through an impermeable stratum to allow water to drain through to a permeable one. Also called absorbing well, drain well, negative well.

decomposition of wastewater – (1) The breakdown of organic matter in wastewater by bacterial action, either aerobic or anaerobic. (2) Transformation of organic or inorganic materials contained in wastewater through the action of chemical or biological processes.

degradation of organic material – Reduction of the complexity of a chemical compound by biological action.

degree of treatment – A measure of the removal effected by treatment processes with reference to solids, organic matter, BOD, bacteria, or any other specified matter.

de-ionized water – Water that has been treated by ion exchange resins to remove cations and anions present in the form of dissolved salts.

denitrification – (1) The conversion of oxidized nitrogen (nitrate and nitrite-N) to nitrogen gas by contact with septic wastewater solids or other reducing chemicals. (2) A reduction process with respect to oxidized nitrogen.

deoxygenation – The depletion of the dissolved oxygen in a liquid either under natural conditions associated with the biochemical oxidation of organic matter present or by addition of chemical reducing agents.

desalination, desalting – Total or partial removal of salt from salt water.

detention tank – A tank used in water or wastewater treatment to provide adequate time for chemical or physical reactions to take place in the body of liquid being treated.

defoamant, defoaming agent – A material having low compatibility with foam and a low surface tension. Defoamants are used to control, prevent, or destroy various types of foam, the most widely used being silicone defoamers. A droplet of silicone defoamant which contacts a bubble of foam will cause the bubble to undergo a local and drastic reduction in film strength, thereby breaking the film. Unchanged, the defoamant continues to contact other bubbles, thus breaking up the foam. A valuable property of most defoamants is their effectiveness in extremely low concentration. In addition to silicones, defoamants for special purposes are based on polyamides, vegetable oils, and stearic acids.

detention time, detention period – The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

detergent – (1) Any of a group of synthetic, organic, liquid or water-soluble cleaning agents that are inactivated by hard water and have wetting-agent and emulsifying-agent properties but, unlike soap, are not prepared from fats and oils. (2) A similar substance that is soluble in oil and capable of holding insoluble foreign matter in suspension. (3) Any cleansing agent, including soap.

detritus – (1) The coarse debris carried by wastewater. (2) The heavier mineral debris moved by natural watercourses, usually in bed-load form.

dialysis – The separation of a colloid from a substance in true solution by allowing the solution to diffuse through a semipermeable membrane.

diatomaceous earth, diatomite – A fine, siliceous earth consisting mainly of the skeletal remains of diatoms (unicellular organisms).

diffused-air aeration– Aeration produced by introducing air through porous media into a liquid. Sufficient air pressure must be applied to overcome hydrostatic head and diffuser or pipe backpressure.

diffuser – A porous plate, tube, or other device through which air is forced and divided into minute bubbles for diffusion in liquids. Commonly made of carborundum, alundum, metal, or plastic materials.

digested sludge – Sludge digested under either aerobic or anaerobic conditions until the volatile content has been reduced to the point at which the solids are relatively nonputrescible and inoffensive.

digester – A tank in which sludge is placed to permit digestion to occur. Also called sludge digestion tank. See *sludge digestion.*

digestion – (1) As commonly used, digestion refers to the anaerobic decomposition of organic matter in sludge, resulting in partial gasification, liquefaction and mineralization. (2) The process carried out in a digester. Also see following terms modifying digestion: *Anaerobic, high-rate, sludge.*

digestion tank – A *digester.*

dilution factor, dilution ratio – The ratio of the water of a stream to the incoming waste; the capacity of a stream to assimilate waste is partially dependent upon the dilution ratio; in a waste-treatment plant design, the dilution ratio is the ratio of the maximum waste flow actually treated to the dry weather flow of the plant.

direct oxidation – The direct combination of substances with oxidants accomplished without benefit of living organisms. For example, oxidation of substances in wastewater by the direct application of air or oxidizing agents such as chlorine.

discharge – (1) As applied to a stream or conduit, the rate of flow, or volume of water flowing in the stream or conduit at a given place and within a given period of time. (2) The passing of water or other liquid through an opening or along a conduit or channel. (3) The rate of flow of water, silt, or other mobile substances which emerges from an opening, pump, or turbine, or passes along a conduit or channel, usually expressed as cubic feet per second, gallons per minute, or million gallons per day.

disinfection – The art of killing the larger portion of micro-organisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

dispersed growth – Non-flocculating micro-organisms whose presence in treated wastewater results in a turbid effluent.

dissolved oxygen (DO) – The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation. Abbreviated DO. In unpolluted water, oxygen is usually present in amounts up to 10 ppm. Adequate dissolved oxygen is necessary for the life of fish and other aquatic organisms. About 3-5 ppm is the lowest limit for support of fish life over a long period of time.

dissolved-oxygen sag curve – A curve that represents the profile of dissolved oxygen content along the course of a stream resulting from deoxygenation associated with biochemical oxidation of organic matter and reoxygenation through the absorption of atmospheric oxygen and biological photosynthesis. Also called oxygen-sag curve.

dissolved solids (DS) – The total amount of dissolved material, organic and inorganic, contained in water or wastes. Excessive dissolved solids can make water unsuitable for industrial uses, unpalatable for drinking, and even cathartic. Potable water supplies may have dissolved solid content from 20 to 1000 mg/l, but sources which have more than 500 mg/l are not recommended by the U.S. Public Health Service.

distilled water – Water formed by the condensation of steam or water vapor.

distributor – A device used to apply liquid to the surface of a filter or contact bed. Distributors are of two general types, fixed and movable. The fixed type may consist of perforated pipes, notched troughs, sloping boards, or sprinkler nozzles. The movable type may consist of rotating, reciprocating, or traveling perforated pipes or troughs applying a spray or a thin sheet of liquid.

ditch oxidation – A modification of the activated sludge process or the aerated pond, in which the mixture under treatment is circulated in an endless ditch and aeration and circulation are produced by a mechanical device such as Kessener brush.

DO – Abbreviation for *dissolved oxygen.*

domestic consumption – The quality, or quantity per capita, of water supplied in a municipality or district for domestic uses or purposes during a given period, usually one day. It is usually taken to include all uses included within the term municipal use of water and quantity wasted, lost, or otherwise unaccounted for.

domestic garbage – The portion of garbage resulting from the preparation, cooking, and dispensing of food in homes, hotels, clubs, and restaurants.

domestic sewage (wastewater) – Wastewater derived principally from dwellings, business buildings, institutions, and the like. It may or may not contain groundwater, surface water, or storm water.

drain tile – (1) Pipes of various materials, in short lengths, laid in covered trenches underground, in most cases quite loosely and with open joints, to collect and carry off excess groundwater or to dispose of wastewater on the ground. Agricultural drain is ordinarily made with plain ends. (2) A vitrified tile underdrainage system laid on the bottom to support trickling filter stone, sand or other filter media including sludge drying beds. These are specially prepared blocks or half tiles containing slots for passage of water or air but restricting bed media penetration.

drinking-water standards – (1) Standards prescribed by the U.S. Public Health Service for the quality of drinking water supplied to interstate carriers. (2) Standards prescribed by state or local jurisdictions for the quality of drinking water supplied from surface-water, groundwater, or bottled-water sources.

drum screen – A screen in the form of a cylinder or truncated cone which rotates on its axis.

dry-weather flow – (1) The flow of wastewater in a combined sewer during dry weather. Such flow consists mainly of wastewater, with no storm water included. (2) The flow of water in a stream during dry weather, usually contributed entirely by ground water. Also see *base flow.*

DS – Abbreviation for *dissolved solids.*

E. coli – Abbreviation of *Escherichia coli,* a species of bacteria in the coliform group and normal inhabitants of the intestine of man and all vertebrates. Its presence is considered indicative of fresh fecal contamination.

ecology – The branch of biology dealing with the relationship between organisms and their environment.

eductor – A device for mixing air with water; a liquid pump operating under a jet principle, using liquid under pressure as the operating medium to entrain air in the liquid.

efficiency – The relative results obtained in any operation in relation to the energy or effort required to achieve such results. It is the ratio of the total output to the total input, expressed as a percentage.

effluent – (1) A liquid which flows out of a containing space. (2) Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, or part thereof. (3) An outflowing branch of a main stream or lake.

electrical conductivity – The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature. It expressed as micromhos per centimeter at temperature degrees Celsius. See *specific conductance.*

electrodialysis – Process for removing ionized salts from water through the use of ion-selective ion-exchange membranes.

elutriation – A process of sludge conditioning whereby the sludge is washed with either fresh water or plant effluent to reduce the demand for conditioning chemicals and to improve settling or filtering characteristics of the solids. Excessive alkalinity is removed in this process.

end point – The stage in a titration at which equivalence is attained and revealed by a change that can be observed or measured, such as color development, formation of a precipitate, or reaching a specified pH.

enzyme – A catalyst produced by living cells. All enzymes are proteins, but not all proteins are enzymes.

equalizing basin – A holding basin in which variations in flow and composition of a liquid are averaged. Such basins are used to provide a flow of reasonably uniform volume and composition to a treatment unit. Also called balancing reservoir.

erosion – The wearing away of land surface by various natural agencies, the most important being water, in the form of seas, rivers, rain, glacial ice, hoarfrost, and melting snow.

Escherichia coli (E. coli) – One of the species of bacteria in the coliform group. Its presence is considered indicative of fresh fecal contamination.

estuarine – Of, pertaining to, or formed in an estuary.

estuary – The mouth of a river, where tidal effects are evident and where fresh water and sea water mix.

eutrophic lake - Lake or other contained water body rich in nutrient. Characterized by a large quantity of planktonic algae, low water transparency with high dissolved oxygen in upper layer, zero dissolved oxygen in deep layers during summer months, and large organic deposits colored brown or black. Hydrogen sulfide often present in water and deposits.

eutrophication – The normally slow aging process by which a lake evolves into marsh and ultimately becomes completely filled with detritus and disappears. In the course of this process the lake becomes overly rich in dissolved nutrients (for example, nitrogen and phosphorus), so that an excessive development of algae results. First the water becomes murky, the noxious odors and unsightly scums appear. In the lower layers dissolved oxygen levels become depressed, and bottom-dwelling fauna change from clean-water forms to pollution-tolerant forms.

evaporation rate – The quantity of water, expressed in terms of depth of liquid water, evaporated from a given water surface per unit of time. It is usually expressed in inches depth per day, month, or year.

evapotranspiration – Water withdrawn from soil by evaporation and/or plant transpiration.

extended aeration – A modification of the activated sludge process which provides for aerobic sludge digestion within the aeration system. The concept envisages the stabilization of organic matter under aerobic conditions and disposal of the end products into the air as gases and with the plant effluent as finely divided suspended matter and soluble matter.

facultative bacteria – Bacteria that can adapt themselves to growth and metabolism under aerobic or anaerobic conditions. Many organisms of interest in wastewater stabilization are among this group.

fats – Triglyceride esters of fatty acids. Naturally occuring compounds functioning as storage products in the living organism. Generally semi-solid or oily at normal temperatures. Erroneously used as synonymous with grease.

fauna – The animals of a given region or period considered as a whole.

fermentation – (1) A change brought about by a ferment, as yeast enzymes. (2) Changes in organic matter or organic wastes brought about by micororganisms growing in the absence of air.

field capacity – (1) The quantity of water held in a soil by capillary action after gravitational water is removed. It is the moisture content of a soil, expressed as a percentage of the oven-dry weight, after the gravitational or free water has been allowed to drain, usually for two to three days. (2) The field moisture content two or three days after a soaking rain. (3) The moisture content to which each layer of soil must be raised before water can drain through it.

field moisture capacity – The approximate quantity of water which can be permanently retained in the soil in opposition to the downward pull of gravity. It may be expressed in percentage of dry weight or in inches depth for a given depth of soil. The length of time required for a soil to reach field moisture capacity varies considerably with various soils, being approximately 24-48 hr for sandy soils, 5-10 days for silt-clay soils, and longer for clays. Also called capillary capacity, field carrying capacity, maximum water-holding capacity, moisture-holding capacity, normal moisture capacity.

field permeability coefficient – The rate of flow of water, in gallons per day, under prevailing conditions, through each food of thickness of a given aquifer in a width of one mile, for each foot per mile of hydraulic gradient. Also called hydraulic conductivity.

fill – (1) Any material deposited by any agent so as to fill or partly fill a channel, valley, sink, or other depression. May be prefixed by a word describing its dominant grain size or its method of deposition. (2) The volume of material to be added. (3) An embankment. (4) Material used to raise the existing ground elevation.

filter – A device or structure for removing solid or colloidal material, usually of a type that cannot be removed by sedimentation, from water, wastewater, or other liquid. The liquid is passed through a filtering medium, usually a granular material but sometimes finely woven cloth, unglazed porcelain, or specially prepared paper. There are many types of filters used in water or wastewater treatment. See *trickling filter.*

filter clogging – The effect occuring when fine particles fill the voids of a sand filter or biological bed or when growths form surface mats that retard the normal passage of liquid through the filter.

filter cloth – Fabric, wire or other material stretched over the drum of a vacuum filter and accessories, i.e., to support the solids during cake formation and discharge solids when and where desired.

filtered wastewater – Wastewater that has passed through a mechanical filtering process but not through a trickling filter bed.

filter efficiency – The operating results from a filter as measured by various criteria such as percentage reduction in suspended matter, total solids, biochemical oxygen demand, bacteria, color.

filter loading – Organically, the pounds of biochemical oxygen demand (BOD) in the applied liquid per unit of filter bed area or volume per day. Hydraulically, the quantity of liquid applied per unit of filter bed area or volume per day.

filter medium – Any material through which water, sewage or other liquid is passed for purification purposes by chemical, biological or physical processes.

filter plant – (1) In water treatment works, the processes, devices, and structures used for filtration of water. (2) In wastewater treatment units, the devices and structures required to provide trickling filtration.

filter ponding, filter pooling – The formation of pools of wastewater as a result of surface clogging of filters.

filter press – A press operated mechanically for partially separating water from solid materials. See *press filter.*

filter press cake – A residual waste product (as, for example, from the process of grease recovery following the wool scouring process); filter-press cake may contain organic matter, dirt, grit, or other residue.

filter rate – The rate of application of material to some process involving filtration, for example, application of wastewater sludge to a vacuum filter, wastewater flow to a trickling filter, water flow to a rapid sand filter.

filter unloading – The periodic or continuous sloughing of the biological film on the filter stones of a trickling filter.

filtrate – The liquid which has passed through a filter.

filtration – The process of passing a liquid through a porous medium for the removal of suspended or colloidal material contained in the influent liquid by a physical straining action. The trickling filter process used in wastewater treatment is a method of contacting dissolved and suspended organic matter with biologically active aerobic slime growths, and hence is not a true filtration process.

filtration rate – The rate of application of wastewater to a filter, usually expressed in million gallons per acre per day or gallons per minute per square foot.

final effluent – The effluent from the final treatment unit of a wastewater treatment plant.

final settling tank (basin), final clarifier – A tank through which the effluent from a trickling filter or an aeration or contact-aeration tank is passed to remove the settleable solids. See *sedimentation basin.*

first-stage biochemical oxygen demand – That part of oxygen demand associated with biochemical oxidation of carbonaceous, as distinct from nitrogenous, material. Usually, the greater part, if not all, of the carbonaceous material is oxidized before the second stage, or substantial oxidation of the nitrogenous material, takes place. Nearly always, at least a portion of the carbonaceous material is oxidized before oxidation of nitrogenous material even starts.

five-day BOD – That part of oxygen demand associated with biochemical oxidation of carbonaceous, as distinct from nitrogenous, material. It is determined by allowing biochemical oxidation to proceed, under conditions specified in Standard Methods, for 5 days. See *first-stage biochemical oxygen demand.*

fixed charge – (1) The carrying and operating cost of any business or project which continues to occur whether or not the business operates or produces anything. (2) A charge that cannot be escaped, shifted, or altered, such as interest, rent, taxes, and amortization.

fixed solids – The residue remaining after ignition of suspended or dissolved matter according to standard methods.

flat rate – A charge for water or sewer service that is not based on metered quantity. It may be based on size of service pipe, number of water fixtures or outlets, land frontage, or other arbitrary measures, usually fixed by law.

float control (switch/valve) – Commonly a device to control a pump or pumps according to the water level in a chamber or well as indicated by the float. Usually operates a relay to control pump power, number or speed of pumps in operation.

floc – Gelatinous or amorphous solids formed by chemical, biological, or physical agglomeration of fine materials into large masses that are more readily separated from the liquid.

flocculation – In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical of hydraulic means. In biological wastewater treatment where coagulation is not used, agglomeration may be accomplished biologically.

flocculator – (1) A mechanical device to enhance the formation of floc in a liquid. (2) An apparatus for the formation of floc in water and wastewater.

flood irrigation – A process of wastewater disposal in which wastewater is applied to a depth of about one foot, by means of distributors, on a land area surrounded by low earth embankments. This procedure allows the wastewater to percolate through the soil to the underdrains, whence it is discharged into a main ditch or drain.

flora – The plants of a particular region or period, listed by species and considered as a whole.

flotation – The raising of suspended matter to the surface of the liquid in a tank as scum – by aeration, the evolution of gas, chemicals, electrolysis, heat, or bacterial decomposition – and the subsequent removal of the scum by skimming.

flume – (1) A long narrow channel for gravity flow of liquid from one point to another. An open conduit of wood, masonry, or metal constructed on a grade and sometimes elevated. (2) To transport in a flume, as fruits or vegetables.

foam fractionation/separation – The planned frothing of wastewater or wastewater effluent as a means of removing excessive amounts of detergent materials, through the introduction of air in the form of fine bubbles. Also called foam fractionation.

force main – A pressure pipe joining the pump discharge at a water or wastewater pumping station with a point of gravity flow.

fouling – A gelatinous, slimy accumulation on the waterway of a conduit, resulting from the activity of organisms in the waters. Fouling is more easily removable than tuberculation. Fouling may be found on concrete, masonry, and metal surfaces, but tuberculation is found on only metal surfaces.

free available chlorine – Generally includes that chlorine existing in water as the hypochlorous acid. Characterized by rapid color formation with orthotolidine, can be titrated in a neutral solution with phenyl arsene oxide and produces a rapid organism kill in low concentrations.

freeboard – The vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of an open conduit, the top of a dam or levee, etc., which is provided so that waves and other movements of the liquid will not overtop the confining structure.

free residual chlorination – The application of chlorine or chlorine compounds to water or wastewater to produce a free available chlorine residual directly or through the destruction of ammonia or certain organic nitrogenous compounds.

fresh sludge – Recently deposited and removed sludge from sedimentation tanks that has not been conditioned, processed or progressed materially into anaerobic action.

fresh wastewater – Wastewater of recent origin containing dissolved oxygen.

fungi – Small non-chlorophyll-bearing plants which lack roots, stems, or leaves, which occur (among other places) in water, wastewater, or wastewater effluents and grow best in the absence of light. Their decomposition after death may cause disagreeable tastes and odors in water; in some wastewater treament processes they are helpful and in others they are detrimental.

furrow irrigation – A method of applying irrigation water to fields or orchards by small ditches or furrows which lead from the supply ditch.

gaging – The determination of the quantity of water flowing per unit of time in a stream channel, conduit, or orifice at a given point by means of current meters, rod floats, weris, Pitot tubes, or other measuring devices or methods.

garbage – The animal and vegetable waste resulting from the handling, preparation, cooking, and serving of foods. It is composed largely of putrescible organic matter and its natural moisture content.

gasification – The transformation of soluble and suspended organic materials into gas during waste decomposition.

gel – A form of matter in a colloidal state that does not dissolve, but nevertheless remains suspended in a solvent from which it does not precipitate without the intervention of heat or of an electrolyte.

germicidal treatment – Any treatment involving killing of microorganisms through the use of disinfecting chemicals.

grassed waterway – An area of grass over which runoff water can move in a thin sheet across the land surface and thus proceed more slowly than it does when it moves across cultivated crops, hence causing less erosion.

grating – A screen consisting of parallel bars, two sets being transverse to each other in the same plane.

gravity separator – See *catch basin.*

gravity system – (1) A system of conduits (open or closed) in which the liquid runs on descending gradients from source to outlet, and where no pumping is required. (2) A water-distribution system in which no pumping is required.

grease – in wastewater, a group of substances including fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and certain other nonfatty materials. The type of solvent and method used for extraction should be stated for quantitation.

grease-removal tank – A tank designed to facilitate the flotation of oil and grease, provided with a device for removal.

gridiron system – (1) A system of water pipes in which all pipes are interconnected with all other pipes at street intersections to permit the maximum capability of flow throughout the system. (2) A form of layout of a system of drains, generally used for flat lands or lands with a uniform slope, where the field drains are constructed in parallel lines along the direction of the slope and join the main drain at its bottom.

grit – The heavy suspended mineral matter present in water or wastewater, such as sand, gravel, cinders.

grit chamber – An enlargement of a channel designed to reduce flow velocity adequately to permit differential separation of sand and grit from organic suspended material. Usually approaches a linear flow velocity of 1 to 3 ft./sec.

ground cover – Any vegetation producing a protecting mat on or just above the soil surface.

groundwater – Subsurface water occupying the saturation zone, from which wells and springs are fed. In a strict sense the term applies only to water below the water table. Also called phreatic water, plerotic water.

groundwater level – The level below which the rock and subsoil, down to unknown depths, are saturated with water.

hard detergent – A synthetic detergent which is resistant to biological attack. See *ABS*.

hardness – A characteristic of water, imparted by salts of calcium, magnesium, and iron such as bicarbonates, carbonates, sulfates, chlorides and nitrates, that causes curdling of soap and increased consumption of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes objectionable taste. It may be determined by a standard laboratory procedure or computed from the amounts of calcium and magnesium as well as iron, aluminum, manganese, barium, strontium, and zinc, and is expressed as equivalent calcium carbonate. Soft water is that with less than 60 ppm of salts; temporary water, 60 to 120 ppm; permanent water, in excess of 120 ppm.

header – (1) A structure installed at the head or upper end of a gully to prevent overfall cutting. (2) A supply ditch for the irrigation of a field. (3) A large pipe installed to intercept the ends of a series of pipes; a manifold. (4) The closing plate on the end of a sewer lateral which will not be used immediately.

herringbone system – A system of drains, usually used for lands lying on both sides of a narrow depression or swale, and consisting of a main or subdrain along the depression with parallel lines of field drains sloping toward the main drain and joining it at staggered intervals.

high-rate digestion – Accelerated anaerobic digestion resulting primarily from thorough mixing of digester contents. May be enhanced by thermophilic digestion.

high-rate filter – A trickling filter operated at a high average daily dosing rate, usually between 10 and 40 mgd/acre including any recirculation of effluent.

household wastes – The water-carried wastes from kitchens, toilets, lavatories, and laundries.

humus – The dark-colored carboniferous residue in the soil resulting from the decomposition of vegetable tissues of plants originally growing therein. Residues similar in appearance and behavior are found in well-digested sludges and in activated sludge.

hydrogen-ion concentration – The weight of hydrogen ion in moles per liter of solution. Commonly expressed as the pH value, which is the logarithm of the reciprocal of the hydrogen-ion concentration.

hydrologic cycle – The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration. Also called water cycle.

hydrology – The applied science concerned with the waters of the earth in all their states – their occurrence, distribution, and circulation through the unending hydrologic cycle of precipitation, consequent runoff, streamflow, infiltration, and storage, eventual evaporation, and reprecipitation. It is concerned with the physical, chemical, and physiological reactions of water with the rest of the earth and its relation to the life of the earth.

hydrolysis – (1) The reaction of a solute with water in aqueous solution. (2) A change in the chemical composition of matter produced by combination with water. Sometimes loosely applied in wastewater practice to the liquefaction of solid matter in a tank as a result of biochemical activity.

Imhoff one – A cone-shaped graduated glass vessel used to measure the approximate volume of settleable solids in various liquids of wastewater origin during various settling times.

Imhoff tank – A deep, two-storied wastewater tank originally patented by Karl Imhoff. It consists of an upper continuous-flow sedimentation chamber and a lower sludge-digestion chamber. The floor of the upper chamber slopes steeply to trapped slots through which solids may slide into the lower chamber. The lower chamber receives no fresh wastewater directly, but is provided with gas vents and with means for drawing digested sludge from near the bottom.

immediate biochemical oxygen demand – (1) The initial quantity of oxygen used by polluted liquid immediately upon being introduced into water containing dissolved oxygen. It may be exercised by end products of prior biochemical action or by chemical substances avid for oxygen. (2) In the standard laboratory procedure, the apparent BOD for 15 minutes at 20°C.

impermeable, impervious – Not allowing, or allowing only with great difficulty, the movement of water; impervious and/or impermeable.

implementation plan – A schedule for improving waste treatment to comply with established water quality criteria.

impoundment – A pond, lake, tank, basin, or other space, either natural or created in whole or in part by the building of engineering structures, which is used for storage, regulation, and control of water.

index organisms – Microscopic organisms the presence or absence of which in bodies of water indicates presence or absence and extent of pollution or other specific factor under study.

indicator – (1) A device that shows by an index, pointer, dial, etc., the instantaneous value of such quantities as depth, pressure, velocity, stage, or the movements or positions of water-controlling devices; a gage. (2) A substance giving a visible change, usually of color, at a desired point in a chemical reaction, generally at a prescribed end point.

indirect discharge measurement – A determination of the peak discharge, (other than by current meter) by the slope-area, contracted-opening, culvert, flow-over-dam, or critical-depth methods. An indirect measurement is usually based on a survey of high-water marks after a flood.

industrial wastes – The liquid wastes from industrial processes, as distinct from domestic or sanitary wastes.

industrial wastewater – Wastewater in which industiral wastes predominate. See *domestic wastewater, industrial wastes.*

industry water requirements – The quantity of water required to produce a unit of product. It is the quantity of water ordinarily used and not necessarily the minimum that could be used.

infiltration – (1) The penetration of water through the soil from surface precipitation, stream or impoundment boundaries. (2) The entrance of groundwater into a sewer through breaks, defective joints or porous walls. See *percolation, seepage.*

rounding permeable soil. (4) The loss of soluble constituents from fruits, vegetables, or other material into water or other liquid in which the material is immersed. (5) The escaping of free moisture from a solid waste land disposal site into the surrounding environment, frequently causing odors and other nuisance conditions of public health significance.

linear alkylate sulfonate (LAS) – The biodegradable or "soft" surfactant which replaced ABS as the major surfactant component of household synthetic detergents in the U.S. Actually, an ABS type, but with a straight rather than branched alkyl side chain. This terminology was adopted to distinguish it from polypropylene-derived ABS.

liquefaction – (1) Act or process of liquefying or of rendering or becoming liquid; reduction to a liquid state. (2) Act or process of converting a solid or a gas to a liquid state by changes in temperature or pressure, or the changing of the organic matter in wastewater from a solid to a soluble state.

liquid chlorine – Elemental chlorine placed in a liquid state by a combination of compression and refrigeration of dry, purified chlorine gas. Liquid chlorine is shipped under pressure in steel containers.

load curve – A curve that expresses the variation of the load on an electric generating plant or system, water or wastewater pumping station, or treatment plant over a given period of time, such as a day, week, month, year. The load is usually plotted as the ordinate and time as the abscissa.

load factor – The ratio of the average load carried by an operation to the maximum load carried, during a given period of time, expressed as a percentage. The load may consist of almost anything; examples are electrical power, number of persons served, amount of water carried by a conduit.

loading – The quantity of waste, expressed in gallons (hydraulic load) or in pounds of BOD, COD, suspended or volatile solids (organic load) which is discharged to a wastewater treatment facility.

low-rate filter – A trickling filter designed to receive a small load of BOD per unit volume of filtering material and to have a low dosage rate per unit of surface area, usually one to four million gallons per day per acre, and generally without recirculation. Organic loading (BOD) rate is usually in the range of 5 to 25 lb/1,000 cu ft. Also called standard-rate filter.

lysimeter – A structure containing a mass of soil and designed to permit the measurement of water draining through the soil.

main-line meter – A water meter installed on a large main of the distribution system.

make-up water – Water added to circulating water in a system to replace water lost by evaporation, leakage, or blowdown. See *recirculation.*

manhole – An opening by which access may be achieved for inspection, maintenance or repair of a sewer, conduit or other buried structure or appurtenance.

maximum capacity – In waste-treatment plants, either the maximum rate at which wastewater can be put through a plant hydraulically, or some lower rate established by the management (such as the maximum rate at which wastewater can be treated without seriously interrupting the treatment process).

mechanical aeration – (1) The mixing, by mechanical means, of wastewater and activated sludge in the aeration tank of the activated sludge process to bring fresh surfaces of liquid into contact with the atmosphere. (2) The introduction of atmospheric oxygen into a liquid by the mechanical action of paddle, paddle wheel, spray, or turbine mechanisms.

membrane filtration – A method of quantitative or qualitative analysis of bacterial or particulate matter in a water sample by filtration through a membrane capable of retaining bacteria.

mesh – One of the openings or spaces in a screen. The value of the mesh is usually given as the number of openings per linear inch. This gives no recognition to the diameter of the wire, and thus the mesh number does not always have a definite relation to the size of the hole.

mesophilic range – Operationally, that temperature range most conducive to the maintenance of optimum digestion by mesophilic bacteria, generally accepted as between 27° and 32° C (80° and 90°F).

methane fermentation – Fermentation resulting in conversion of organic matter into methane gas.

mgd – Abbreviation for million gallons per day.

mg/l – Abbreviation for milligrams per liter.

microbial film – A gelatinous film of microbial growth attached to or spanning the interstices of a support medium. Also called biological slime.

milli – An expression used to indicate 1/1000 of a standard metric unit of weight, length or capacity. Examples:

milligram (mg)	1/1000 gram (g)
millimeter (mm)	1/1000 meter (m)
milliliter (ml)	1/1000 liter (1)

milligrams per liter – A unit of the concentration of water or wastewater constituent. It is 0.001 g of the constituent in 1,000 ml of water. It has replaced the unit formerly used commonly, parts per million, to which it is approximately equivalent, in reporting the results of water and wastewater analysis.

mixed liquor – A mixture of activated sludge and organic matter undergoing activated sludge treatment in the aeration tank.

MLVSS – Abbreviation for mixed liquor volatile suspended solids, the quantity of solids contained in the mixed liquor of an activated sludge treatment system which is lost on ignition of the dry solids at 600°C. This value is an index of the active biological mass within the treatment system.

modified aeration – A modification of the activated sludge process in which a shortened period of aeration is used with a reduced quantity of suspended solids in the mixed liquor.

moisture content – The quantity of water present in soil, wastewater sludge, industrial waste sludge, and screenings, usually expressed in percentage of wet weight.

most probably number (MPN) – That number of organisms per unit volume that, in accordance with statistical infiltration rate – The rate at which water can enter the soil. Units of expression are usually inches of water per day.

influent – Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

inorganic matter – Chemical substances of mineral origin, or more correctly, not of basically carbon structure.

intercepting sewer – An intercepting sewer designed to carry the dry weather flow from a community to a treatment plant but not large enough to carry storm water above some pre-set ratio to dry weather flow. May be used to collect lateral sewer flows.

intermediate treatment – Wastewater treatment such as aeration or chemical treatment, supplementary to primary treatment. Such treatment removes substantial percentages of very finely divided particulate matter, in addition to the suspended solids removed by primary treatment. Supplementary processing improves the efficiency of treatment so that about 60 percent of both BOD and suspended solids are removed.

interstate waters – All rivers, lakes, and other waters that flow across or form a part of state boundaries, including coastal waters.

interstice – A pore or open space in rock or granular material, not occupied by solid matter. It may be occupied by air, water, or other gaseous or liquid material. Also called void, void space.

intrastate waters – Streams, rivers, lakes, and other waters whose flow or periphery is within the boundaries of one state.

inverse sludge index – Properly called sludge density index. It is the reciprocal of the sludge volume index multiplied by 100.

inverted siphon – A pipeline crossing a depression or passing under a structure and having a reversal in grade on a portion of the line, thus creating a V- or U-shaped section of conduit. The line is under positive pressure from inlet to outlet and should not be confused with a siphon. Also called depressed sewer.

investment tax credit – in pollution abatement, reduction in a company's tax by a given percent of the sum invested in pollution abatement equipment and facilities.

iodometric chlorine test – The determination of residual chlorine in water or wastewater by addition of potassium iodide and titration of the liberated iodine with a standard solution of sodium thiosulfate, with starch solution as a colorimetric indicator.

ion-exchange – (1) A chemical process involving reversible interchange of ions between a liquid and a solid but no radical change in structure of the solid. (2) A chemical process in which ions from two different molecules are exchanged. (3) Ion-exchange treatment of water or wastewater involves the use of ion-exchange materials such as resin or zeolites to remove undesirable ions from a liquid and substitute acceptable ions.

iron bacteria – Bacteria that either utilize iron as a source of energy or cause its dissolution or deposition. The former obtain energy by oxidizing ferrous iron to ferric iron, which is precipitated as ferric hydrate; the latter, without oxidizing ferrous iron, alter environmental conditions in such a way as to cause it to be dissolved or deposited.

irrigation – The artificial distribution of water on the land in order to (a) facilitate the cultivation of crops where otherwise, owing to a deficiency of rainfall, agriculture would be impossible or difficult, or (b) increase or enhance the yield in areas where rainfall is adequate but supplementary distribution of water at certain critical periods in the development of the crop is advantageous, or (c) to facilitate the disposal of wastewater, which may or may not have been previously treated, through percolation, evaporation and/or plant transpiration.

Jeris rapid COD test – A chemical test to measure the relative pollutional strength of wastewater samples. Organic matter contained in wastewater is digested in an acidic oxidizing solution by heating to 165°C. This requires but a few minutes compared to the refluxing period of one-half to two hours specified by *Standard Methods*.

Kraus process – A modification of the activated sludge process in which aerobically conditioned supernatant liquor from anaerobic digesters is added to activated sludge aeration tanks to improve the settling characteristics of the sludge and to add an oxygen resource in the form of nitrates.

lagoon – An all-inclusive term commonly given to a water impoundment in which organic wastes are stored or stabilized, or both. Lagoons may be described by the predominant biological characteristics (aerobic, anaerobic, or facultative), by location (indoor, outdoor), by position in a series (primary, secondary, or other), and by the organic material accepted (sewage, sludge, manure, or other).

lagooning – The placement of solid or liquid material in a basin, reservoir or artificial impoundment for purposes of storage, treatment, or disposal.

land disposal – (1) Disposal of wastewater onto land by spray or surface irrigation. (2) Disposal of solid waste materials by incorporating the solid waste into the soil by cut-and-fill techniques or by sanitary land-fill operations.

land use – (1) The culture of the land surface, which has a determining effect on the broad social and economic conditions of a region and which determines the amount and character of the runoff and erosion. Three general classes are recognized: crop, pasture or range, and forest. (2) Existing or zoned economic use of land, such as residential, industrial, farm, commercial.

LAS – Linear alkylate sulfonate.

lateral sewer – A sewer that discharges into a branch or main sewer and has no other tributaries other than individual connections.

leaching – (1) The removal of soluble constituents from soils or other material by percolating water. (2) The removal of salts and alkali from soils by abundant irrigation combined with drainage. (3) The disposal of a liquid through a non-watertight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surtheory, would be more likely than any other number to yield the observed test result or that would yield the observed test result with the greatest frequency. Expressed as density of organisms per 100 ml. Results are computed from the number of positive findings of coliform-group organisms resulting from multiple-portion decimal-dilution plantings.

multiple use – The management of land and water resources taking into account the many human demands on them with a view to all necessary and desirable uses; these demands change in nature and number through time.

multiple-purpose development – In water projects, development that takes into account the use and control of water in all possible aspects: irrigation, power, flood control, domestic and industrial water supply, pollution control, navigation, recreation, fish and wildlife. The first multiple-purpose project authorized and designed as such was the Boulder Canyon Project (Hoover Dam), 1928.

natural pollution – Soil, mineral, or bacterial impurities picked up by water from the earth's surface, apart from any human activity.

natural purification – Natural processes occurring in a stream or other body of water that result in the reduction of bacteria, satisfaction of the BOD, stabilization of organic constituents, replacement of depleted dissolved oxygen, and the return of the stream biota to normal. Also called self-purification.

navigable water – Any stream, lake, arm of the sea, or other natural body of water that is actually navigable and that, by itself or by its connections with other waters, is of sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, or even pleasure for a period long enough to be of commercial value; or any waters that have been declared navigable by the Congress of the United States.

neutralization – Reaction of acid or alkali with the opposite reagent until the concentrations of hydrogen and hydroxyl ions in the solution are approximately equal.

nitrification – (1) The conversion of nitrogenous matter into nitrates by bacteria. (2) The treatment of a material with nitric acid.

nitrogen cycle – A graphical presentation of the conservation of matter in nature, from living animal matter through dead organic matter, various stages of decomposition, plant life, and the return of living animal matter, showing changes which occur in course of the cycle. It is used to illustrate biological action and also aerobic and anaerobic acceleration of the transformation of this element by wastewater and sludge treatment.

nitrogenous wastes – Wastes of animal or plant origin that contain a significant concentration of nitrogen.

nonconsumptive use (of water) – Water use in which only a small portion is lost to the atmosphere by evapotranspiration or by being combined with a manufactured product. Nonconsumptive use returns to the stream or ground approximately the same amount of water as is diverted or used.

nonionic surfactant – A general family of surfactants so called because in solution the entire molecule remains associated. Nonionic molecules orient themselves at surfaces not by an electrical charge, but through separate grease-solubilizing and water-soluble groups within the molecule.

nonsettleable solids – Wastewater matter that will stay in suspension for an extended period of time. Such period may be arbitrarily taken for testing purposes as one hour. See *suspended solids.*

normality – A means of expressing the concentration of a standard solution in terms of the gram equivalents of reacting substance per liter.

nutrient – A chemical substance (an element or a chemical compound) absorbed by living organisms and used in organic synthesis. The major nutrients include carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus. Nitrogen and phosphorus are of major concern because they tend to recycle and are difficult to remove from water due to their solubility.

odor control – (1) In water treatment, the elimination or reduction of odors in a water supply by aeration, algae elimination, super-chlorination, activated carbon treatment, and other methods. (2) In wastewater treatment, the prevention or reduction of objectionable odors by chlorination, aeration, or other processes or by masking with chemical aerosols.

oils – (1) Liquid fats of animal or vegetable origin. (2) Oily or waxy mineral oils.

organic matter – Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structure, comprising compounds consisting of hydrocarbons and their derivatives.

organic nitrogen – Nitrogen combined in organic molecules such as proteins, amines, and amino acids.

orthotolidine chlorine test – A technique for determining residual chlorine in water by using orthotolidine reagent and colorimetric standards. The dye, orthotolidine, under highly acid conditions produces a yellow color proportional in intensity to the concentration of available residual chlorine. It is used for routine measurement; however, its accuracy is affected by interfering substances and color.

osmosis – The flow or diffusion through a semipermeable membrane separating unlike substances in the course of which the concentrations of the components on the two sides of the membrane are equalized; especially the passage of solvent (usually water), in distinction from the passage of solute.

outfall – (1) The point, location, or structure where wastewater or drainage discharges from a sewer, drain, or other conduit. (2) The conduit leading to the ultimate disposal area. Also see *wastewater outfall.*

overflow rate – One of the criteria for the design of settling tanks in treatment plants; expressed in gallons per day per square foot of surface area in the settling tank.

overturning – The phenomenon of vertical circulation which occurs in large bodies of water. It is due to the increase in density of water below and above 39.2°F, the temperature of maximum density. In the spring, as the surface of the water warms above the freezing point, the water increases in density, becomes heavier, and tends to sink, producing vertical currents, while in the fall, as the surface water becomes colder and therefore heavier, it also tends to sink. Wind may also create such vertical currents.

oxidation – Chemically – the addition of oxygen, removal of hydrogen or the removal of electrons from an element or compound.

oxidation pond – A basin used for retention of wastewater before final disposal, in which biological oxidation of organic materials is effected by natural or artifically accelerated transfer of oxygen to the water from air.

oxidation process (treatment) – Any method of wastewater treatment for the oxidation of the putrescible organic matter. The usual methods are biological filtration and the activated sludge process. Living organisms in the presence of air are utilized to convert the organic matter into more stable or mineral form.

oxidation rate – The rate at which the organic matter in wastewater is stabilized.

oxygenation capacity – In treatment processes, a measure of the ability of an aerator to supply oxygen to a liquid.

oxygen balance – (1) The dissolved-oxygen level at any point in a stream, resulting from the opposing forces of deoxygenation and reaeration. (2) The relation between the biochemical oxygen demand of a wastewater or treatment plant effluent and the oxygen available in the diluting water.

oxygen deficiency – (1) The additional quantity of oxygen required to satisfy the oxygen requirement in a given liquid. Usually expressed in milligrams per liter. (2) Lack of oxygen.

oxygen demand – (1) The quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. See *BOD*.

oxygen depletion – Loss of dissolved oxygen from water or wastewater resulting from biochemical or chemical action.

oxygen-sag curve – A curve that represents the profile of dissolved oxygen content along the course of a stream, resulting from deoxygenation associated with biochemical oxidation of organic matter and reoxygenation through the absorption of atmospheric oxygen and through biological photosynthesis. Also called dissolved-oxygen-sag curve.

ozone – Oxygen in molecular form with three atoms of oxygen forming each molecule (O_3).

paddle aerator – A device, similar in form to a paddle wheel, that is used in aeration of water.

Parshall flume – A calibrated device developed by Parshall for measuring the flow of liquid in an open conduit. It consists essentially of a contracting length, a throat, and an expanding length. Flows through the device are determined by measuring the head of water at a specific distance from a sill over which water passes. See *venturi flume.*

particulate matter – Refers to detectable solid materials dispersed in a gas or liquid. Small sized particulates may produce a smoky or hazy appearance in a gas, milky or turbid appearance in a liquid. Larger particulates are more readily detected and separated by sedimentation or filtration.

parts per million (ppm) – The number of weight or volume units of a minor constituent present with each one million units of the major constituent of a solution or mixture. Formerly used to express the results of most water and wastewater analyses, but more recently replaced by the ratio milligrams per liter.

pathogenic bacteria – Bacterial, fungal, viral, or other organisms directly involved with diseases of plants, animals, or man are included among this group.

P.E. – Abbreviation for *population equivalent.*

peak load – (1) The maximum demand for water placed on a pumping station, treatment plant, or distribution system, expressed as a rate. (2) The maximum rate of flow of wastewater to a pumping station or treatment plant. Also called peak demand.

percolation – (1) The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may or may not fill the pores of the medium. Also called filtration. (2) The movement or flow of water through the interstices or the pores of a soil or other porous medium. (3) The water lost from an unlined conduit through its sides and bed.

permeability – (1) The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. Perviousness is sometimes used in the same sense as permeability. (2) The capacity of a rock or rock material to transmit a fluid.

pesticide – An agent (usually a chemical) used to destroy pests. Pesticides present in ground and surface waters as a result of direct application, runoff, percolation, or manufacturing discharge may have grave adverse effects on water quality. Careless use of pesticides may result in fish kills.

pH – The reciprocal of the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen-ions, in grams, per liter of solution. pH values reflect the balance between acids and alkalies. The extreme readings are 0 and 14. The pH of most natural waters falls within the range 4 to 9. Neutral water, for example, has a pH value of 7.0 and a hydrogen-ion concentration of 10^{-7} Slight decrease in pH may greatly increase the toxicity of substances such as cyanides, sulfides, and most metals. Slight increase may greatly increase the toxicity of pollutants such as ammonia. Alkaline water will tend to form a scale, acid water is corrosive.

plankton – The aggregate of passively floating, drifting, or weakly motile organisms in a body of water. The organisms are mostly microscopic.

pollution – Contamination or other alteration of the physical, chemical, or biological properties of water, including changes in temperature, taste, color, or odor of the water, or the discharge into the water of any liquid, gaseous, radioactive, solid, or other substance that may create a nuisance or render such water detrimental or injurious to public health, safety, or welfare. Broadly, pollution means any change in water quality that impairs it for the subsequent user.

pollutional index – A criterion by which the degree of pollution of a stream or other body of water may be measured, such as bacterial density, plankton, benthos, biochemical oxygen demand, dissolved oxygen, or other index of water quality.

pollutional load – (1) The quantity of material in a waste stream that requires treatment or exerts an adverse effect on the receiving system. (2) The quantity of material carried in a body of water that exerts a detrimental effect on some subsequent use of that water.

polymer – Any one of several commercially available high-molecular-weight, water-soluble polymeric flocculation agents. When added to water, these substances form a flocculent precipitate which will agglomerate or coagulate suspended matter and expedite sedimentation.

population equivalent – A means of expressing the strength of organic material in wastewater. Domestic wastewater consumes, on an average, 0.17 lb of oxygen per capita per day, as measured by the standard BOD test. This figure has been used to measure the strength of organic industrial waste in terms of an equivalent number of persons. For example, if an industry discharges 1,000 pounds of BOD per day, its waste is equivalent to the domestic wastewater from 6,000 persons (1,000 ÷ 0.17 = 6,000).

porosity – The capacity of rock or soil to contain water. The amount of water that rock can contain depends on the open spaces between the grains or cracks that can fill with water. Well-sorted soil is more porous than poorly-sorted soil. Soil is well sorted if the grains are all about the same size (as in the case of gravel or sand); spaces account for a large proportion of the total volume. Soil is poorly sorted if the grains are not all the same size; spaces between larger grains will fill with small grains instead of with water. Poorly-sorted rock thus holds less water than well-sorted.

postchlorination – The application of chlorine to water or wastewater subsequent to any treatment, including prechlorination.

potable water – Water that does not contain objectional pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.

ppm – Abbreviation for *parts per million.*

preaeration – A preparatory treatment of wastewater consisting of aeration to remove gases, add oxygen, promote flotation of grease, and aid coagulation.

prechlorination – The application of chlorine to water or wastewater prior to any treatment.

precipitate – The formation of solid particles in a solution, or the solids that settle as a result of chemical or physical action that caused solids separation.

precipitation – Any form of water, whether liquid or solid, that falls to the ground from the atmosphere; it includes drizzle, rain, snow, snow pellets, snow grains, ice crystals, ice pellets, and hail; the amount of precipitation is usually expressed in inches of equivalent liquid water depth at a given point over a specified period of time.

preliminary filter – A filter used in a water treatment plant for the partial removal of turbidity before final filtration. Such filters are usually of the rapid type, and their use allows final filtration at a more rapid rate or reduces or removes the necessity of other preliminary treatment of the water. Also called contact filter, contact roughing filter, roughing filter. See *roughing filter.*

preliminary treatment – (1) The conditioning of a waste at its source before discharge, to remove or to neutralize substances injurious to sewers and treatment processes or to effect a partial reduction in load on the treatment process. (2) In the treatment process, unit operations, such as screening and comminution, that prepare the liquor for subsequent major operations.

presettling – The process of sedimentation applied to a liquid before subsequent treatment.

press filter – A press operated mechanically for partially dewatering sludge. See *filter press.*

primary settling tank – The first settling tank for the removal of settleable solids through which wastewater is passed in a treatment works.

primary treatment – (1) The first major (sometimes the only) treatment in a wastewater treatment works. Commonly considered to include bar racks, grit chambers, comminution, sedimentation and sludge digestion treatment operations, may include flocculation or disinfection. (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter.

process water – Water (liquid or vapor) that comes in contact with an end product or with materials incorporated in an end product.

proportional composite sample. A combination of individual samples of water or wastewater taken at selected intervals, generally hourly for some specified period, to minimize the effect of the variability of the individual sample. Prior to combination, each individual sample is roughly proportioned to the flow at time of sampling.

protein – (1) Any of the complex nitrogenous compounds formed in living organisms which consist of amino acids bound together by the peptide linkage. (2) Any of a group of nitrogenous organic compounds of high molecular weight synthesized by plants and animals that, upon hydrolysis of enzymes, yield amino acids and that are required for all life processes in animal metabolism.

putrefaction – Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

putrescibility – (1) The relative tendency of organic matter to undergo decomposition in the absence of oxygen. (2) The susceptibility of wastewaters, effluent, or sludge to putrefaction. (3) In water or wastewater analysis, the stability of a polluted water or raw or partially treated wastewater.

rack – A device fixed in place and used to return or remove suspended or floating solids from wastewater and composed of parallel bars evenly spaced. See *screen.*

rapid sand filter – A filter for the purification of water, in which water that has been previously treated, usually by coagulation and sedimentation, is passed downward through a filtering medium. The medium consists of a layer of sand, prepared anthracite coal, or other suitable material, usually 24-30 in. thick, resting on a supporting bed of gravel or a porous medium such as carborundum. The filtrate is removed by an underdrainage system which also distributes the wash water. The filter is cleaned periodically by reversing the flow of the water upward through the filtering medium, sometimes supplementing by mechanical or air agitation during washing, to remove mud and other impurities which have lodged in the sand. It is characterized by a rapid rate of filtration, commonly from two to three gallons per minute per square foot of filter area.

rated capacity – The rate of wastewater flow that a treatment plant is considered capable of treating on a continuous basis with proper disposal of sludge and no loss in efficiency.

reaeration – The absorption of oxygen into water under conditions of oxygen deficit.

receiving waters – A natural watercourse, lake, or ocean into which treated or untreated wastewater is discharged.

recirculation – (1) In the wastewater field, the refiltration of all or a portion of the effluent in a trickling filter to maintain a uniform high rate through the filter. Return of a portion of the effluent to maintain minimum flow is sometimes called recycling. (2) The return of effluent to the incoming flow. (3) The return of the effluent from a process, factory, or operation to the incoming flow to reduce the water intake. The incoming flow is called makeup water.

recycling – An operation in which a substance is passed through the same series of processes, pipes, or vessels more than once.

reduction – (1) To make smaller or to remove from a given amount of material. (2) Chemistry – The removal of oxygen, addition of hydrogen or the addition of electrons to an element or compound. (3) Biology – to degrade complex organic materials.

reoxygenation – The replenishment of oxygen in a stream from dilution water entering the stream, biological reoxygenation through the activities of certain oxygen-producing plants, and atmospheric reaeration.

residual chlorine – Chlorine remaining in water or wastewater at the end of a specified contact period as combined or free chlorine.

retention period – The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge). Also called detention time.

return sludge – Sludge returned from process to the influent flow. Commonly return activated sludge from a secondary clarifier. Also may include sludge from a clarifier after trickling filtration.

return flow – That part of irrigation water that is not consumed by evapotranspiration and returns to its source or runs off into another body of water.

"reverse incentive" – In effect, a penalty connected with water use, such as a user charge (based on the amount of water withdrawn from the municipal supply) or an effluent charge (based on the quantity and quality of wastes discharged into a watercourse) to cover damages caused by a user's pollutants.

reverse osmosis – A process in which, if pressure is put on the concentrated side of a liquid system in which liquids with different concentrations of mineral salts are separated by a semipermeable membrane, molecules of pure water pass out of the concentrated solution to the weak or fresh-water side (contrary to the case of normal osmosis).

riparian water right – The legal right that assures to the owner of land abutting on a stream or other natural body of water the use of such water. It originated in the Common Law, which allowed each riparian owner to require the waters of a stream to reach his land "undiminished in quantity and unaffected in quality" except for minor domestic uses. It has been abrogated in a number of the western states, and greatly modified in others, and, in general, now allows each riparian owner to make a reasonable use of the water on his riparian land, the extent of such use being governed by the reasonable needs and requirements of other riparian owners and the quantity of water available.

riprap – Broken stone or boulders placed compactly or irregularly on dams, levees, dykes, or similar embankments for protection of earth surfaces against the action of waves or currents.

river basin – The area drained by a river and its tributaries. The river basin concept treats each river system, from its head-waters to its mouth, as a single unit. This concept recognizes the inter-relationship of resource elements in a single basin, and assumes that multiple-purpose development can take this inter-relationship into account. It extends the principle of ecological balance to the whole of the area and its occupants.

roughing filter – In wastewater treatment, a trickling filter containing coarse material or plastic medium operated at a high rate to afford partial treatment preliminary to a secondary treatment operation. By using a roughing filter, the organic loading imposed on the subsequent biological system is significantly reduced.

runoff – (1) That portion of rainfall or melted snow which runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer. Runoff is faster and greater during heavy rain than during protracted drizzle, on clay soils than on sandy soils, on frozen soils than on frostless soils, in treeless areas than in forests. The ratio between runoff and rainfall varies considerably with climatic conditions. (2) Total quantity of runoff water during a specified time. (3) In the general sense, that portion of the precipitation which is not absorbed by the deep strata, but finds its way into the streams after meeting the persistent demands of evapotranspiration, including interception and other losses. (4) The discharge of water in surface streams, usually expressed in inches depth on the drainage area, or as volume in such terms as cubic feet or acre-feet.

saline contamination – Contamination of water by intrusion of salt water.

saline water – Water containing dissolved salts – usually from 10,000 to 33,000 mg/l.

salinity – (1) The relative concentration of salts, usually sodium chloride, in a given water. It is usually expressed in terms of the number of parts per million of chlorine (Cl). (2) A measure of the concentration of dissolved mineral substances in water.

salt-water intrusion – The invasion of a body of fresh water by a body of salt water. It can occur in either surface or groundwater bodies. The balance between the two under static conditions is expressed in the principle of the U-tube. Also called salt-water encroachment.

sampler – A device used with or without flow measurement to obtain an aliquot portion of water or waste for analytical purposes. May be designed for taking single sample (grab), composite sample, continuous sample, periodic sample.

sand filter – A filter in which sand is used as a filtering medium. Also see *rapid sand filter, slow sand filter.*

sanitary sewer – A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground-, storm, and surface waters that are not admitted intentionally. See *wastewater.*

saponification – The reaction in which caustic combines with fat or oil to produce soap.

saprophytic bacteria – Bacteria that thrive on dead organic matter.

saturation – Commonly refers to the maximum amount of any material that can be dissolved in water or other liquid at a given temperature and pressure. For oxygen this commonly refers to a percentage saturation in terms of the saturation value such as about 9 mg O_2/l at 20^oC.

screen – A device with openings, generally of uniform size, used to retain or remove suspended or floating solids in flowing water or wastewater and to prevent them from entering an intake or passing a given point in a conduit. The screening element may consist of parallel bars, rods, wires, grating, wire mesh, or perforated plate, and the openings may be of any shape, although they are usually circular or rectangular.

screenings – Material removed from liquids by screens.

scum – (1) The layer or film of extraneous or foreign matter that rises to the surface of a liquid and is formed there. (2) A residue deposited on a container or channel at the water surface. (3) A mass of solid matter that floats on the surface.

scum baffle – A vertical baffle dipping below the surface of wastewater in a tank to prevent the passage of floating matter. Also called scum board.

scum breaker – A device installed in a sludge digestion tank to disperse surface accumulations. Generally accomplished by means of mechanical agitation, gas or liquid recirculation that minimizes stratification.

scum collector – A mechanical device for skimming and removing scum from the surface of a settling tank.

secchi disc – A device used to measure the transparency of surface waters. The result obtained by the use of this device is a qualitative indication of the turbidity of the water and is expressed in terms of metric length.

secondary settling tank (clarifier) – A tank through which effluent from some prior treatment process flows for the purpose of removing settleable solids. See *sedimentation tanks.*

secondary wastewater treatment – The treatment of wastewater by biological methods after primary treatment by sedimentation. Common methods of treatment include trickling filtration, activated sludge processes, and oxidation.

second-foot – Obsolete term. See *cubic foot per second (cfs).*

second-stage biochemical oxygen demand – That part of the oxygen demand associated with the biochemical oxidation of nitrogenous material. As the term implies, the oxidation of the nitrogenous materials usually does not start until a portion of the carbonaceous material has been oxidized during the first stage.

sediment – (1) Solid material settled from suspension in a liquid. (2) Inorganic or organic particles originating from weathering, chemical precipitation, or biological activity.

sedimentation – The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. Also called settling.

sedimentation basin/tank – A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation tank, settling basin, settling tank.

sediment concentration – The ratio of the weight of the sediment in a water-sediment mixture to the total weight of the mixture. Sometimes expressed as the ratio of the volume of sediment to the volume of mixture. It is dimensionless and is usually expressed in percentage for high values of concentration and in parts per million for low values.

seepage – (1) Percolation of water through the lithosphere. Definitive meaning usually is described by an adjective such as influent, effluent. See *infiltration.* (2) The slow movement of water through small cracks, pores, interstices, of a material into or out of a body of surface or subsurface water. (3) The loss of water by infiltration from a canal, reservoir, or other body of water, or from a field. It is generally expressed as flow volume per unit time. During the process of priming, such loss is called absorption loss.

self-cleansing velocity. The minimum velocity in sewers necessary to keep solids in suspension, thus preventing their deposition and subsequent nuisance from stoppages and odors of decomposition.

self-purification – The natural processes occurring in a stream or other body of water that result in the reduction of bacreria, satisfaction of the BOD, stabilization of organic constituents, replacement of depleted dissolved oxygen, and the return of the stream biota to normal. Also called natural purification.

separate sewer system – A sewer system carrying sanitary wastewater and other water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground-, storm and surface waters that are not intentionally admitted. See *wastewater.* Also see *combined sewer.*

septicity – A condition produced by growth of anaerobic organisms.

septic wastewater – Wastewater undergoing putrefaction under anaerobic conditions.

sequestering agent – A chemical that causes the coordination complex of certain phosphates with metallic ions in solution so that they may no longer be precipitated. Hexametaphosphates are an example: calcium soap precipitates are not produced from hard water treated with them. Also, any agent that prevents an ion from exhibiting its usual properties because of close combination with an added material. Also see *chelating agent.*

settleable solids – (1) That matter in wastewater which will not stay in suspension during a preselected settling period, such as one hour, but either settles to the bottom or floats to the top. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in one hour.

settled wastewater – Wastewater from which most of the settleable solids have been removed by sedimentation. Also called clarified wastewater.

settling basin/tank – A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, sedimentation tank, settling tank.

settling velocity – The velocity at which subsidence and deposition of the settleable suspended solids in water and wastewater will occur.

sewage – The spent water of a community. Term now being replaced in technical usage by preferable term wastewater. See *wastewater.*

sewage charge – A service charge made for providing wastewater collection and/or treatment service. A specific charge in contrast to an ad valorem tax. Also see *sewage rate.*

sewage rate – A charge, or a schedule of charges, for the collection, or the collection and treatment, of wastewater to users connected to the system, based on water consumption, wastewater flow, wastewater strength, number and types of plumbing fixtures, or some combination.

sewer – A pipe or conduit that carries wastewater or drainage water.

sewerage – System of piping, with appurtenances, for collecting and conveying wastewater from source to discharge. Term declining in use. See *sewer system, wastewater facilities.*

sewer system – Collectively, all of the property involved in the operation of a sewer utility. It includes land, wastewater lines and appurtenances, pumping stations, treatment works, and general property. Occasionally referred to as a sewerage system.

short circuiting – The hydraulic conditions in a tank chamber or basin where time of passage is less than that of the normal flow through period.

skimming tank – A tank so designed that floating matter will rise and remain on the surface of the wastewater until removed, while the liquid discharges continuously under curtain walls or scum boards.

slimes – Substances of viscous organic nature, usually formed from microbiological growth.

sloughing – A phenomenon associated with trickling filters and contact aeration units where slimes build up to a varying degree then slip off into the discharged flow.

slow sand filter – A filter for the purification of water in which water without previous treatment is passed downward through a filtering medium consisting of a layer of sand or other suitable material, usually finer than for a rapid sand filter and from 24 to 40 in. thick. The filtrate is removed by an underdrainage system and the filter is cleaned by scraping off and replacing the clogged layer. It is characterized by a slow rate of filtration, commonly 3-6 mgd/acre of filter area.

sludge – (1) The accumulated solids separated from liquids, such as water or wastewater, during processing, or deposits on bottoms of streams or other bodies of water. (1) The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater.

sludge bed – An area comprising natural or artificial layers of porous material on which digested wastewater sludge is dried by drainage and evaporation. A sludge bed may be open to the atmosphere or covered, usually with a greenhouse-type superstructure. Also called sludge drying bed.

sludge boil – An upwelling of water and sludge deposits caused by release of decomposition gases in the sludge deposits.

sludge bulking – A phenomenon that occurs in activated sludge plants whereby the sludge occupies excessive volumes and will not concentrate readily.

sludge cake – The sludge that has been dewatered by a treatment process to a moisture content of 60-85 percent, depending on type of sludge and manner of treatment.

sludge collector – A mechanical device, including rake, drag, or suction, for collecting settled sludge from the bottom of a clarifier into a sump or other withdrawal system.

sludge conditioning – Treatment of liquid sludge before dewatering to facilitate dewatering and enhance drainability, usually by the addition of chemicals.

sludge density index – The reciprocal of the sludge volume index multiplied by 100.

sludge digestion – The process by which organic or volatile matter in sludge is gasified, liquified, mineralized, or converted into more stable organic matter through the activities of either anaerobic or aerobic organisms.

sludge drying bed – See *sludge bed.*

sludge thickener – A tank or other equipment designed to increase the solids concentration of wastewater sludges.

sludge treatment – The processing of wastewater sludges to render them innocuous. This may be done by aerobic or anaerobic digestion followed by drying on sand beds, filtering, and incineration, filtering and drying, or wet air oxidation.

sludge volume index (SVI) – The ratio of the volume in milliliters of sludge settled from a 1,000-ml sample in 30 min.

standard methods – (1) Methods for the examination of water and wastewater published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation. (2) Methods published by professional organizations and agencies covering specific fields. These include, among others: American Public Health Association, American Public Works Association, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing and Materials, American Water Works Association, United States Bureau of Standards, United States of America Standards Institute (formerly American Standards Association), United States Public Health Service, Water Pollution Control Federation.

standard-rate filter – A type of trickling filter in which both hydraulic and organic loadings are relatively low, usually built to operate without recycling or recirculation of wastewater. See *high-rate filter, low-rate filter, trickling filter.*

step aeration – A procedure for adding increments of settled wastewater along the line of flow in the aeration tanks of an activated sludge plant.

sterilization – The destruction of all living microorganisms, as pathogenic or saprophytic bacteria, vegetative forms, and spores, ordinarily through the agency of heat or of some chemical.

storm drain – A drain used for conveying rainwater, groundwater, subsurface water, condensate, cooling water, or other similar discharge to a storm sewer or combined sewer.

storm sewer – A sewer that carries storm water and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes. Also called storm drain.

storm water – The excess water running off from the surface of a drainage area during and immediately after a period of rain. It is that portion of the rainfall and resulting surface flow that is in excess of that which can be absorbed through the infiltration capacity of the surface of the basin.

strip-cropping – The growing of separate crops in sucessive narrow strips that follow an approximate contour on slopes; such planting retards wind or water erosion.

strip irrigation – A method of irrigation in which the water is applied to a field or orchard that has been divided into a series of strips. The water is applied at the top of the slope and flows downward to the lower end of each strip.

substrate – (1) The substances used by organisms in liquid suspension. (2) The liquor in which activated sludge or other matter is kept in suspension.

subsurface filter – (1) A wastewater sand filter constructed below the surface of the ground and covered with earth to prevent annoyance to nearby dwellings. These filters are often used for disposing of septic tank effluent. (2) In water supply, a gallery of some magnitude, with openings in its sides and bottom, extending generally horizontally into a waterbearing formation to collect the water contained therein.

subsurface irrigation or wastewater disposal – (1) Irrigation by means of underground porous tile or its equivalent. (2) The process of wastewater treatment and disposal in which wastewater or effluent is applied to land by distribution beneath the surface through open-jointed pipes or drains.

sulfur bacteria – Bacteria capable of using dissolved sulfur compounds in their growth; bacteria deriving energy from sulfur or sulfur compounds.

sulfur cycle – A graphical presentation of the conservation of sulfur in nature, living animal matter through dead organic matter, various stages of decomposition, plant life, and the return of living animal matter, showing the changes that occur in this element in course of the cycle. It is used to illustrate biological action as well as aerobic and anaerobic acceleration of the transformation of this element by wastewater and sludge treatment.

sump – (1) A tank or pit that receives drainage and stores it temporarily, and from which the drainage is pumped or ejected. (2) A tank or pit that receives liquids.

superchlorination – Chlorination wherein the doses are deliberately selected to produce free or combined residuals so large as to require dechlorination.

supernatant liquor – (1) The liquor overlying deposited solids. (2) The liquid in a sludge-digestion tank that lies between sludge at the bottom and floating scum at the top.

surface-active agent – The active agent in detergents that possesses a high cleaning ability. These agents in solution exhibit special characteristics that include concentration at interfaces, formation of micelles, solubilization, the lowering of surface tension, and the increased penetration of the liquid in which they are dissolved.

surface aeration – The absorption of air through the surface of a liquid.

surface irrigation – (1) In irrigation, the application of water to the lands by gravity flow through flooding of furrows. (2) In wastewater treatment, the distribution of wastewater over the surface of the ground.

surfactant – A term used to denote a *surface-active agent.*

surge tank – A tank or chamber located at or near a hydroelectric powerhouse and connected with the penstock above the turbine. When the flow of water delivered to the turbine is suddenly decreased, the tank absorbs the water that is held back, and cushions the increased pressure on the penstock which is caused by the rapid deceleration of the water flowing in it; also, when the flow delivered to the turbine is suddenly increased, the tank supplies the increased quantity of water required until the flow in the penstock has been accelerated sufficiently. Also used in connection with pumping systems.

suspended matter – (1) Solids in suspension in water, wastewater, or effluent. (2) Solids in suspension that can be removed readily by standard filtering procedures in a laboratory. See *suspended solids.*

suspended solids – (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering. See *suspended matter.* (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as nonfilterable residue.

to the concentration of mixed liquor in milligrams per liter multiplied by 1,000.

slurry – A watery mixture or suspension of insoluble matter (such as mud, lime, wood pulp).

soap – In general, any product that imparts surface activity to water, including detergent, but chemically and more precisely, the sodium or potassium salt of a fatty acid. Also see *detergent.*

social costs & benefits – Considerations of long-range societal values at the regional or national level which might not be taken into account in the profit and loss statement of an individual farmer, forest operator, industrialist, or other private citizen.

soft detergent – A synthetic detergent that responds to biological attack.

soft water – Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey criteria, soft water is water having a hardness of 60 mg/l or less.

soil porosity – The percentage of the soil (or rock) volume that is not occupied by solid particles, including all pore space filled with air and water. The total porosity may be calculated from the formula: Percent pore space = (1- volume weight/specific gravity) 100

solids-contact clarifier – A unit in which liquid passes upward through a solids blanket and discharges at or near the surface. See *clarifier.*

solids-retention time – The average residence time of suspended soils in a biological waste treatment system, equal to the total weight of suspended solids in the system divided by the total weight of suspended solids leaving the system per unit of time (usually per day).

solute – The substance dissolved in a solution. A solution is made up of the solvent and the solute.

solvent – Liquid used to dissolve a substance.

sparger – An air diffuser designed to give large bubbles, used singly or in combination with mechanical aeration devices.

specific conductance – Measure of a water's capacity to convey an electric current. This property is related to the total concentration of the ionized substances in the water and the temperature of the water. Most inorganic acids, which dissociate readily in aqueous solution, will conduct an electric current well, while organic compounds (such as sucrose and benzene), which do not dissociate in aqueous solution, will conduct a current poorly if at all. See *electrical conductivity.*

specific gravity – The ratio of the mass of a body to the mass of an equal volume of water.

Sphaerotilus – A filamentous, sheath-forming bacterium, often considered the organism responsible for bulking sludge. In polluted streams the presence of this bacterium is evidenced by fibrous growths adhering to rocks and plants along the stream bed.

spray dryer – A form of dryer in which the liquid containing the solids to be dried is sprayed or atomized into a hot chamber.

spray irrigation – A method for disposing of some organic wastewaters by spraying them on land, usually from pipes equipped with spray nozzles. This has proved to be an effective way to dispose of wastes from the canning, meatpacking, and sulfite-pulp industries where suitable land is available.

spray pond – A basin over which water is sprayed from nozzles; generally used for reduction of water temperature.

sprinkler irrigation – Irrigation by means of sprinklers spaced at intervals on a pipe so the areas of influence cover the areas to be irrigated. Pressure for the sprinklers is usually furnished by pumps.

SS – Abbreviation for *suspended solids.*

stability – The ability of any substance, such as wastewater, chemicals, or digested sludge, to resist change. The antonym of *putrescibility.*

stabilization – (1) Maintenance at a relatively nonfluctuating level, quantity, flow, or condition. (2) In lime-soda water softening, any process that will minimize or eliminate scale-forming tendencies. (3) In waste treatment, a process used to equalize wastewater flow composition prior to regulated discharge. (4) In erosion control, treatment of dikes or shorelines with riprap, sod, penetrations, or similar protective devices. (5) In corrosion control, pH adjustment of water to maintain carbonate equilibrium at the saturation point.

stabilization lagoon – A shallow pond for storage of wastewater before discharge. Such lagoons may serve only to detain and equalize wastewater composition before regulated discharge to a stream, but often they are used for biological oxidation. See *stabilization pond.*

stabilization pond – A type of oxidation pond in which biological oxidation of organic matter is effected by natural or artificially accelerated transfer of oxygen to the water from air.

stage aeration – Division of activated sludge treatment into stages with intermediate settling tanks and return of sludge in each stage.

stage treatment – (1) Any treatment in which similar processes are used in series or stages. (2) In the activated sludge process, two or more stages consisting of a clarifying state and a biological state, or two biological states. (3) In anaerobic digestion, an operation in which sludge is completely mixed in the first tank and pumped to a second tank for separation of the supernatant liquor from the solids.

stage trickling filter – A series of trickling filters through which wastewater passes successively with or without intermediate sedimentation.

standard biochemical oxygen demand – Biochemical oxygen demand as determined under standard laboratory procedure for 5 days at 20°C, usually expressed in milligrams per liter.

standardization – (1) The procedure necessary to bring a preparation to a specified or known concentration; for example, preparation and adjustment of a standard solution in volumetric analysis. (2) The comparison of an instrument or device with a standard to determine the relation between results obtained with the instrument or device and those obtained with the standard in terms of an adopted unit.

synthetic detergent – A cleaning agent made synthetically, containing surface-active agents produced by the sulfonation of long-chain alcohols, esters, amides, and alkylbenzenes. Such detergents may be anionic, cationic, or nonionic. See *surface-active agent.*

tapered aeration – The method of supplying varying amounts of air into the different parts of an aeration tank in the activated sludge process, more at the inlet, less near the outlet, in approximate proportion to the oxygen demand of the mixed liquor under aeration.

TBS – (tetrapropylene-benzene sulfonate) – A petrochemical product belonging to the class of synthetic detergents known as alkyl aryl sulfonates. As a surface-active substance it is one of the most useful products developed.

tertiary treatment – Treatment beyond normal or conventional secondary methods for the purpose of increasing water re-use potential.

thermal barrier – An artificial barrier to the passage of migrating fish due to thermal pollution of a water course.

thermal pollution – Impairment of water through temperature change due to geothermal, industrial, or other causes.

thermophilic range – That temperature range most conducive to maintenance of optimum digestion by thermophilic bacteria, generally accepted as between 120° and 135° F.

tile field – A system of open-jointed tile, usually laid on a rock fill, used for dispersing wastewater effluents into the ground. See *subsurface irrigation.*

tile underdrainage – A system of tile drains laid in covered trenches underground, in most cases with open joints, to collect and carry off excess ground water.

tile wastewater-disposal lines – Lines of unglazed open-joint tile placed beneath the ground surface, through which wastewater is dispersed by subsurface disposal. See *subsurface irrigation.*

titration – The determination of a constituent in a known volume of solution by the measured addition of a solution of known strength to completion of the reaction as signalled by observation of an end point.

TOC – Total Organic Carbon. A test expressing wastewater contaminant concentration in terms of the carbon content.

totalizer – A device for indicating the total quantity of flow through a measuring device. Also called integrator.

total solids – Refers to the solids contained in dissolved and suspended form in water. Commonly determined on a weight basis by evaporation to dryness and expressed as milligrams per liter (mg/l).

toxic substance – A substance that either directly poisons living things or alters their environment so that they die. Examples are cyanides found in planting and steel mill wastes, phenols from coke and chemical operations, pesticides and herbicides, and heavy metal salts. Another broad group includes oxygen-consuming substances that upset the balance of nature, such as organic matter from food plants, pulp and paper mills, chemical plants, and textile plants. Still another group are sulfides, produced by oil refineries, smelters, and chemical plants.

transpiration – (1) The process by which water vapor is lost to the atmosphere from living plants. (2) The quantity of water thus dissipated.

transverse drainage – A method of drainage wherein the drains are placed in a direction more or less at right angles to the direction of the steepest slope of the land to be drained.

trash screen – A screen installed or constructed in a waterway to collect and prevent the passage of trash.

tray aerator – An aerator in which the water enters the top tray of a series of perforated trays of equal area and falls as a rain through the air into successively lower trays or collectors.

trickling filter – A structure containing an artificial bed of coarse material, such as broken stone, clinkers, slate, slats, or plastic materials, over which wastewater is distributed or applied in drops, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which the wastewater trickles to the underdrains, giving opportunity for the formation of zoogleal slimes which clarify and oxidize the wastewater. See *filter.*

trickling filter medium – Material, such as stone, clinkers, slate, slats, or plastic materials, used to pack a trickling filter. Zoogleal slimes which oxidize the organic constituents contained in the applied wastewater develop on the surface of the packing medium.

trunk system – A system of major sewers serving as transporting lines and not as local or lateral sewers.

turbidimetry – The measurement of turbidity by using the ratio of the intensity of the light transmitted through the solution to that of the incident light, or the depth at which a target disappears beneath the layer of turbid medium.

turbidity – (1) A condition in water or wastewater caused by the presence of suspended matter, resulting in the scattering and absorption of light rays. (2) A measure of fine suspended matter in liquids. (3) An analytical quantity usually reported in arbitrary turbidity units determined by measurements of light diffraction.

turnover – A phenomenon usually occurring in spring and fall because of the increase in density of water below and above the temperature of maximum density. In the spring, as the surface of the water warms above the freezing point, the water increases in density, becomes heavier, and tends to sink, producing vertical currents, while in the fall, as the surface water becomes colder and therefore heavier, it also tends to sink. Also see *overturning.*

ultimate biochemical oxygen demand – (1) Commonly, the total quantity of oxygen required to satisfy completely the first-stage biochemical oxygen demand. (2) More strictly, the quantity of oxygen required to satisfy completely both the first-stage and the second-stage biochemical oxygen demands.

underdrain – A drain that carries away ground water or the drainage from prepared beds to which water or wastewater has been applied.

underground water – Water that occurs in the lithosphere. It may be in liquid, solid, or gaseous state. It comprises suspended water and ground water. See *groundwater.*

undigested sludge – Settled sludge promptly removed from sedimentation tanks before decomposition has much advanced. Also called raw sludge.

unit water use – The quantity of water used at an industrial plant per unit of production. It may be expressed in gallons per pound, ton, or unit of product.

unloading – The periodic or continuous sloughing of the biological film from the medium on which it has been growing. See *filter unloading, sloughing.*

unsanitary – Contrary to principles known to promote or safeguard health.

upflow contact clarifier – A unit in which water enters the bottom and is discharged at or near the surface. See *clarifer.*

user charge (for water) – A charge for water based on the amount withdrawn from the public supply.

USPHS drinking water standards – Standards prescribed by the U.S. Public Health Service for the quality of drinking water supplied to interstate carriers and prescribed as standards by most state and local jurisdictions for all public water supplies.

vacuum deaeration – Equipment operating under vacuum to remove dissolved gases from liquid.

vacuum filter – A filter consisting of a cylindrical drum mounted on a horizontal axis, covered with a filter cloth, and revolving with a partial submergence in liquid. A vacuum is maintained under the cloth for the larger part of a revolution to extract moisture. The cake is scraped off continuously.

vapor – (1) The gaseous form of any substance. (2) A visible exhalation, such as fog, mist, steam, smoke, diffused through, or suspended in, the air.

vapor pressure – (1) The pressure exerted by a vapor in a confined space. It is a function of the temperature. (2) The partial pressure of water vapor in the atmosphere. (3) Partial pressure of any liquid.

velocity-area method – A method used to determine the discharge of a stream or any open channel by measuring the velocity of the flowing water at several points within the cross section of the stream and summing up the products of these velocities and their respective fraction of the total area.

venturi flume – An open flume with a contracted throat that causes a drop in the hydraulic grade line. It is used for measuring flow. See *Parshall flume.*

venturi meter – A differential meter for measuring flow of water or other fluid through closed conduits or pipes, consisting of a venturi tube and one of several proprietary forms of flow-registering devices. The difference in velocity heads between the entrance and the contracted throat is an indication of the rate of flow. See *venturi tube.*

venturi tube – A closed conduit or pipe, used to measure the rate of flow of fluids, containing a gradual contraction to a throat, which causes a pressure-head reduction by which the velocity may be determined. The contraction is usually, but not necessarily, followed by an enlargement to the original size.

vertical-flow-tank – A sedimentation tank in which water or wastewater enters near the bottom, rises vertically, and flows out at the top. An upflow tank.

viable – Living and potentially reproductive.

virus – The smallest (10-300 $m\mu$ in diameter) form capable of producing infection and diseases in man or other large species. Occuring in a variety of shapes, viruses consist of a nucleic acid core surrounded by an outer shell (capsid) which consists of numerous protein subunits (capsomeres). Some of the larger viruses contain additional chemical substances. The true viruses are insensitive to antibiotics. They multiply only in living cells where they are assembled as compelx macromolecules utilizing the cell's biochemical systems. They do not multiply by division as do intracellular bacteria.

vitrified tile – Drain tile made of ground shale or higher-grade clay, with the surface glazed by the use of salt; usually less porous and more resistant to frost action than ordinary clay tile.

void space – A pore or open space in rock or granular material, not occupied by solid matter. It may be occupied by air, water, or other gaseous or liquid material. Also called interstice, void.

volatile acids – Fatty acids containing six or less carbon atoms, which are soluble in water and which can be steam-distilled at atmospheric pressure. Volatile acids are commonly reported as equivalent to acetic acid.

volatile matter – Apparent loss of matter from a residue ignited at $600^{\circ} \pm 25^{\circ}C$ for a period of time sufficient to reach constant weight of residue, usually 10-15 min. See *volatile solids.*

volatile solids – The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at $600^{\circ}C$.

wash water – Water used to wash filter beds in a rapid sand filter.

waste-disposal plant – (1) A plant equipped for treatment and disposal of waste. (2) An arrangement of devices and structures for treating wastewater, industrial wastes, and sludge. Also see *water pollution control plant.*

waste stabilization pond – An impoundment into which wastewater is discharged at a rate low enough to permit oxidation to occur without substantial nuisance.

waste treatment – Any process to which wastewater or industrial waste is subjected to make it suitable for subsequent use.

waste water – In a legal sense, water that is not needed or that has been used and is permitted to escape, or that unavoidably escapes from ditches, canals, or other conduits, or reservoirs of the lawful owners of such structures. See *wastewater.*

wastewater – The spent water of a community. From the standpoint of source, it may be a combination of the liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with any groundwater, surface water, and storm water that may be present. In recent years, the word wastewater has taken precedence over the word sewage.

wastewater analysis – The determination of chemical composition, concentration, and biological condition of wastewater and treatment plant effluents.

wastewater charge – A service charge made for providing wastewater collection and/or treatment service. A specific charge in contrast to an ad valorem tax. Also see *wastewater rate.*

wastewater composition – (1) The relative quantities of the various solid, liquid, and gaseous constituents of wastewater. (2) The chemical and physical characteristics of the solid and liquid constituents of wastewater, and their relationships apart from the degree of concentration.

wastewater disposal – The act of disposing of wastewater by any method. Not synonymous with wastewater treatment. Common methods of disposal are: dispersion, dilution, broad irrigation, privy, cesspool.

wastewater facilities – The structures, equipment, and processes required to collect, carry away, and treat domestic and industrial wastes, and dispose of the effluent.

wastewater field – The perceptible area created on the surface of a body of water by the discharge of wastewater or industrial wastes. Also called sleek field.

wastewater influent – Wastewater as it enters a wastewater treatment plant or pumping station.

wastewater lagoon – An impoundment into which wastewater is discharged at a rate low enough to permit oxidation to occur without substantial nuisance.

wastewater outfall – The outlet or structure through which wastewater is finally discharged.

wastewater rate – A charge or a schedule of charges for the collection or the collection and treatment of wastewater to users who are connected to the system. It may be based on water consumption, wastewater flow, strength of wastewater, number and type of plumbing fixtures, or some combination of these.

wastewater survey – An investigation of the quality and characteristics of each waste stream, as in an industrial plant or municipality.

wastewater treatment – Any process to which wastewater is subjected in order to remove or alter its objectional constituents and thus render it less offensive or dangerous. See *intermediate treatment, primary treatment.*

wastewater treatment works – (1) An arrangement of devices and structures for treating wastewater, industrial wastes, and sludge. Sometimes used as synonymous with waste treatment plant or wastewater treatment plant. (2) A water pollution control plant.

water – (1) A transparent, odorless, tasteless liquid, a compound of hydrogen and oxygen, H_2O, freezing at 32^oF or 0^oC and boiling at 212^oF or 100^oC, which, in more or less impure state, constitutes rain, oceans, lakes, rivers, and other such bodies; it contains 11.188 percent hydrogen and 88.812 percent oxygen, by weight. It may exist as a solid, liquid, or gas and, as normally found in the lithosphere, hydrosphere, and atmosphere, may have other solid, gaseous, or liquid materials in solution or suspension. (2) To wet, supply, or irrigate with water.

water analysis – The determination of the physical, chemical, and biological characteristics of water. Such analyses usually involve four different kinds of examinations: bacterial, chemical, microscopic, and physical.

water-carriage system – The system of disposing of waste matter from buildings by using water to carry it hydraulically in a piping system.

water consumption – The quantity, or quantity per capita, of water supplied in a municipality or district for a variety of uses or purposes during a given period. It is usually taken to mean all uses included within the term municipal use of water and quantity wasted, lost, or otherwise unaccounted for.

water content – (1) In plant ecology, the water of the soil or habitat; physiological – the available water supply; physical – the total amount of soil water. (2) In soil mechanics, the quantity of water present in soil, wastewater sludge, industrial waste sludge, and screenings, usually expressed in percentage of wet weight. Also called *moisture content.*

watercourse – (1) A natural or artificial channel for passage of water. (2) A running stream of water. (3) A natural stream fed from permanent or natural sources, including rivers, creeks, runs, and rivulets. There must be a stream, usually flowing in a particular direction (though it need not flow continuously) in a definite channel, having a bed or banks and usually discharging into some other stream or body of water.

water cycle – The circuit of water movement from the atmosphere to the earth and return to the atmosphere through varoious stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration. Also called hydrologic cycle.

water meter – A device installed in a pipe under pressure for measuring and registering the quantity of water passing through it.

water of crystallization – The water that combines with salts when they crystallize. It is a definite quantity and a molecular constituent of the crystalline compound.

water pollution control plant – An arrangement of devices and structures for the control of waterborne pollution of waterways. Also referred to as treatment plant, with appropriate adjective describing source of wastewater.

water quality – The chemical, physical, and biological characteristics of water with respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another, depending on its characteristics and the requirements for the particular use.

water quality standards – Limits set by authority on the basis of water quality criteria required for beneficial uses. Limits are imposed on the physical and chemical characteristics required for specific beneficial use.

water rate – (1) The charge for water consumed by consumer per unit of measurement, whether measured by metering or by a flat rate. (2) Amount of water vapor required in a steam plant per unit of energy output, usually expressed in pounds per kilowatt hour.

water rights – The legal powers or privileges recognized as validly existing under the applicable system of law, in, upon, or concerning waters, as such powers or privileges held by nations, states, corporations, or individuals exist in the light of the powers and privileges of others in the same waters.

water rights acquired by prescription – Water rights acquired by the open, actual, notorious, exclusive, long-continued performance of certain acts or operations, which in themselves are detrimental or injurious to the right of another party, performed under claim of right to do them, and with the knowledge of their performance on the part of the other party. The diversion of water by a person at a point upstream from the land of a riparian owner, under these conditions, would give such person a right perfected by prescription to the use of the water as against the lower riparian owner.

watershed – (1) The area contained within a divide above a specified point on a stream. In water supply engineering, it is called a watershed or a catchment area; in river control engineering, it is called a drainage area, a drainage basin, or a catchment area. (2) The divide between drainage basins.

water softening – The process of removing from water, in whole or in part, those cations which produce hardness.

water spreading – The artificial application of water to lands for the purpose of storing it in the ground for subsequent withdrawal by pumps for crops.

water standards – Definitions of water quality established as a basis of control for various water-use classification.

water supply – (1) In general, the sources of water for public or private uses. When U.S. Public Health Service and state standards have been met, the supply is termed "an approved water supply". (2) The furnishing of a good potable water under satisfactory pressure for domestic, commercial, industrial, and public service, and an adequate quantity of water under reasonable pressure for fire fighting.

water table – The upper surface of the zone of saturation, except where that surface is formed by an impermeable body.

water treatment – The filtration or conditioning of water to render it acceptable for a specific use.

water treatment plant – That portion of water treatment works intended specifically for water treatment; may include, among other operations, sedimentation, chemical coagulation, filtration, and chlorination.

water use – A system of classifying utilization of waters in natural watercourses for such purposes as potable water supply, recreation and bathing, fish culture, industrial water, waste assimilation, transportation, power production.

weep hole (weeper) – An opening formed during the construction or retaining walls, aprons, canal linings, foundations, to permit drainage of water collecting behind and beneath such structures to reduce hydrostatic head.

weir – (1) A diversion dam. (2) A device that has a crest and some side containment of known geometric shape, such as a V, trapezoid, or rectangle, and is used to measure flow of liquid. The liquid surface is exposed to the atmosphere. Flow is related to upstream height of water above the crest, to position of crest with respect to downstream water surface, and to geometry of the weir opening.

wet oxidation process – A method of sludge disposal that involves the oxidation of sludge solids in water suspension and under increased pressure and temperature.

wetting – A process by which a liquid is adsorbed by a solid surface and forms a liquid film thereon that wets the surface.

wet well – A compartment in which a liquid is collected, and to which the suction pipe of a pump is connected.

wind direction – The point of the compass from which the wind blows (not that toward which it is moving).

wing screen – A screen in which the screening elements are set in radial planes of curved vanes, rotating on a horizontal axis.

workable sludge – Sludge that can be readily forked or shoveled from a sludge drying bed. Ordinarily under 75 percent moisture.

works – A group or assemblage of physical devices and structures for any of a variety of useful purposes; for example, water treatment plant, wastewater or industrial waste treatment plant, wastewater pumping station. See *sewer system, wastewater treatment works, water supply system.*

yeasts – A broad group of fungal microorganisms capable of causing fermentation.

zeolite – A group of hydrated aluminum complex silicates, either natural or synthetic, with cation-exchange properties. Also see *ion exchange, zeolite process.*

zeolite process – The process of softening water by passing it through a substance known in general as a zeolite, which exchanges sodium ions for hardness constituents in the water.

zooglea – A jelly-like matrix developed by bacteria. A major part of activated sludge floc and of trickling filter slimes.

zoogleal matrix – The floc formed primarily by slime-producing bacteria in the activated sludge process or in biological beds.

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