Industrial Waste Audit and Reduction Manual

A practical guide to developing and conducting a manufacturing process survey for waste minimization opportunities

3rd Edition

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OWMC is a provincial Crown agency created by an act of the Ontario legislature in 1981 to establish a provincial system for treating and disposing of liquid industrial and hazardous wastes. OWMC provides industry with waste reduction, reuse and recycling assistance.

OWMC
HAZARDOUS WASTE REDUCTION AND TREATMENT SPECIALISTS

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Chapter 1: Introduction to Waste Auditing and Reduction

What is a waste audit?

The in-plant survey or waste audit is the first step in reducing waste and overcoming pollution problems. It is a detailed analysis of your company's processes and wastes aimed at minimizing, or even eliminating, discharges from unit processes.

Carrying out a waste audit involves observing, measuring and recording process-related data, asking questions around the plant and collecting and analyzing waste samples. To be effective it must be done methodically and thoroughly under the direction of a dedicated waste reduction supervisor who has been freed from all other production and administrative duties. The audit should also involve personnel from top management to shop floor workers.

A good waste audit should:

- define sources, quantities and types of waste being generated
- bring together information on unit processes, products, raw materials, water usage and waste generation
- highlight process efficiencies and inefficiencies
- identify areas of wastage and loss and waste problems
- identify the constituents of waste
- help set targets for waste reduction
- permit development of cost-effective waste management strategies
- increase employee knowledge of production processes and appreciation for waste reduction benefits

Why reduce wastes?

The days of cheap resources, low energy costs and few environmental regulations are gone for good. Companies today are taking a closer look at how to reduce their wastes and thereby cut their costs, and to comply with increasingly strict regulations.

Tighter regulations governing waste disposal, particularly Regulation 347 of Ontario's Environmental Protection Act, coupled with escalating costs of disposal, are the two greatest incentives for industry to cut down on waste production.

The Ontario Ministry of Environment and Energy's Municipal and Industrial Strategy for Abatement (MISA) is putting an end to one method of disposal. Limits will be placed on the total amounts of contaminants (by weight) which municipal treatment facilities and industrial generators can discharge to sewers, rivers and lakes. Industries and municipalities not meeting these limits will be forced to either upgrade their treatment facilities or, more likely, reduce the amount of wastes discharged to the sewers.

Some plants are complying with these restrictions by treating the total plant effluent. This approach tends to be very costly and can be much less effective than reducing wastes at source. End-of-pipe treatment often entails large volumes of dilute wastes which contain complex mixtures of process waste materials. The resulting treatment processes tend to require a great deal of attention. It is often difficult to destroy or to remove a high percentage of all contaminants. Often, it is far better to move back up the pipe and identify and segregate waste streams at their source for treatment or reuse.

Getting Started

It costs a company manpower and money to carry out a waste audit and therefore senior management support is essential. Obviously the reader of this manual, if he/she is a staff employee, will have to present sound reasons in order to obtain such support. These could include:

- reduced waste generation
- reduced raw material consumption
- reduced waste treatment costs
- reduced potential liability
- improved public relations
- enhanced process efficiency resulting in improved company profits.

When writing to senior management for approval, be specific. Tell supervisors where you suspect losses are occurring or where you think money can be saved. Of course the hard data you need to back up your suspicions can only be obtained by carrying out the audit, but in many cases projections can be enough to induce management to allocate the resources you need.

An audit can be successful only through employee involvement and cooperation. This means that employees must be assured the audit will be a non-blaming process and they will not be punished for poor operating practices. If employees feel management is looking for scapegoats, they will not cooperate. It is important to tell employees why the audit is being carried out (for example, the exercise is part of a continuous improvement program) and to let all concerned know the results of the audit once it has been completed. It is important to set goals; quantitative goals are preferable to qualitative ones. For instance, your company could adopt a goal of seven per cent waste reduction annually with the eventual goal of zero discharge by a specified year. Cash or other incentives for ideas resulting in improved efficiency and waste reduction could be offered to employees.

The number of people on an audit team will depend on the size and complexity of the plant. An audit team for a larger plant could consist of three or four people: an environmental specialist, a production employee and one or two technical people from a sister plant who are perhaps involved in research and development, maintenance or consulting. The size of the team is not critical. In a small plant the owner may wish to conduct the audit with input from employees. If possible, the leader of the audit team should be freed from other duties until the audit is completed. Frequently the necessary data for an audit can be collected in less than two weeks. Interpretation of the results will take additional time. In other cases an audit could take longer depending on a number of factors such as the size of the plant and the focus of the audit (i.e., the level of detail, the number of plant operations to be examined and so forth). This is all up to the reader.

This manual is designed to be used by staff at all levels—technical as well as non-technical. It is a practical guide to help you understand your processes. Apply this manual to your individual situation and focus on concept rather than the details. For example, Step 5 records water usage. If you don't use much water, there may be no need to spend time collecting data just to fill in Table 4. Because the manual is generic, its approach can be applied to the entire spectrum of manufacturing activities.

It is important at the outset to select a focus for your audit. For example your audit could concentrate on wastes which fit any of the following criteria:

- costly to dispose of
- generated from expensive raw materials
- require specialized handling methods
- considered to be hazardous or regulated
- easy to reduce.

The audit should be conducted with production processes in normal operation and during working hours so that questions can be asked of employees.

The audit will be a snapshot in time. Processes change and the plant tomorrow will not operate in exactly the same manner as it does today. Therefore, a more realistic picture will be obtained if the audit is conducted over a period of time to average out daily input and output fluctuations. Furthermore a new audit should be performed whenever major changes occur, such as:

- changes in the price of raw materials
- changes in regulations
- changes in the cost of disposal
- process changes.

Chapter 2: An Approach

Overview

This chapter describes an approach to conducting the waste audit. It is designed to be generic in nature to apply to as broad a spectrum of industry as possible. As you go through the 18 steps, it may become obvious that some parts do not apply to your particular circumstances. You may also require additional or modified steps for your individual needs. If this is the case, then adapt as necessary. However, the following approach is sound and should form the basis of your investigations.

The waste audit/waste reduction approach is divided into six phases and incorporates a number of steps as follows:

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes
Step 2: Constructing a process flow diagram

Phase Two: Defining process inputs

Step 3: Determining resource usage
Step 4: Investigating raw material storage and handling losses
Step 5: Recording water usage
Step 6: Determining current levels of waste reuse

Phase Three: Defining process outputs

Step 7: Quantifying process outputs
Step 8: Accounting for wastewater flows
Step 9: Documenting wastes stored and hauled off-site for disposal

Phase Four: The material balance study

Step 10: Assembling unit process input and output information
Step 11: Deriving a preliminary material balance for unit processes
Step 12: Evaluating the material imbalance
Step 13: Refining the material balance

Phase Five: Identifying waste reduction alternatives

Step 14: Examining obvious waste reduction measures
Step 15: Targeting problem waste streams
Step 16: Developing long-term waste reduction alternatives

Phase Six: Cost/ benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction
Step 18: Implementing the action plan: reducing wastes and increasing production efficiency

The following section describes the 18 steps. It should be emphasized that although the auditing procedures are described as discrete steps, the audit needs to be thoroughly planned and developed into an efficient and integrated approach. For example, Phases Two and Three should be run concurrently. It may also be worthwhile to refer to the case studies as you progress through the audit.

Phase One of the waste audit involves going into the plant and developing a sound understanding of all the process components and their interrelationships. It is worthwhile at this stage to solicit help from staff who are familiar with the day-to-day operations of the plant.

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes

A plant might consist of many unit processes. The first step in the waste audit is to identify and list all the unit processes and then assemble as much information about how the units operate and how the units are connected as possible. A unit process can be defined as an area of the plant or a piece of equipment where materials go in, something happens and materials come out, possibly in a different form, state or composition. It may be grinding, painting, plating, dyeing, filtering, warehousing or it may be the waste treatment system.

A walk through the plant will help the audit team decide how to describe plant production in terms of unit processes. During this walk through, it may be very helpful to sketch a line drawing of processes, sewers, drains, vents and other material transfer areas. By doing this you will be less likely to miss important input and output data. Part of the walk through involves asking questions of foremen and operators about processing and waste generating operations such as spills, clean-ups, rinses and washes.

A plant tour may disclose that actual material handling practices are different from those in written procedures. During the walk through note immediate problems that need to be addressed before the audit is completed.

Start the audit with something easy. The level of detail is up to you. A whole plant, a processing building, an area, one piece of equipment or an entire production line could be targeted. If you can't get all the information about a particular process without a lot of work and plumbing changes, perhaps you can get the material input and output information for the building the process is located in. This level of detail may be sufficient.

Record information on unit processes in a table similar to Table 1 and begin developing a file of all existing information. For the sake of keeping records, assign a name to each unit process. Use your discretion as to the level of detail collected. It may be necessary to concentrate on certain problem areas to start with. For example, in the first case study in Chapter 3, the complexity of the plant was such that the waste audit was carried out with specific reference to copper—the contaminant causing major problems with respect to sewer discharge compliance. However, before you decide to narrow the scope of the audit, ensure that the scoping is done with a sound understanding of the process involved.

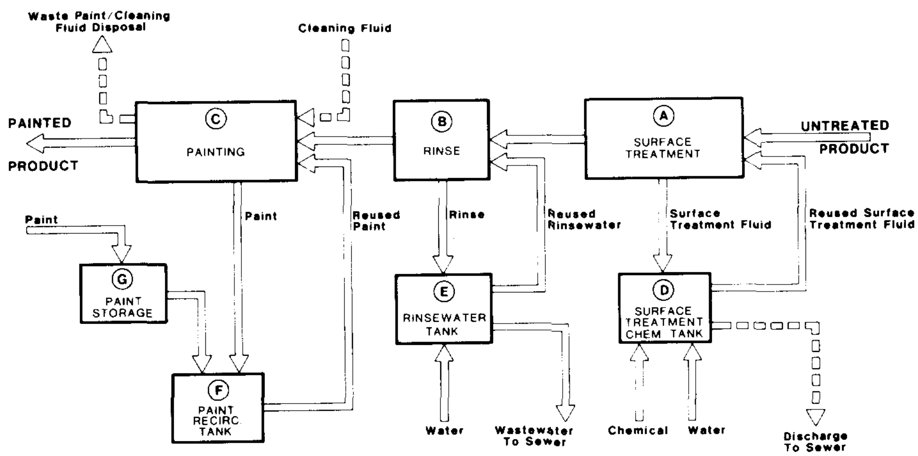
Table 1: Identification of unit processes

Unit Process	*Functional Description*	*File Number*
e.g. Surface Treatment (A) products before painting -10 m^3 spray chamber -6 jets, 100 L/m pump	-Surface treatment of metal	1
(B) etc.		2

Step 2: Constructing a process flow diagram

By interconnecting the individual unit processes in the form of a block diagram you will have prepared a process flow diagram. Intermittent operations such as cleaning, make-up, or tank dumping should also be included in the process flow diagram and can be identified by broken lines and labelling. Figure 1 is an example of a simplified process flow diagram.

Figure 1: Example of process flow diagram



With complex processes it is recommended that you not try to include every unit process in a single process flow diagram. Instead, prepare a general flow diagram describing the main processing areas and on separate sheets of paper prepare detailed flow diagrams of each main processing area.

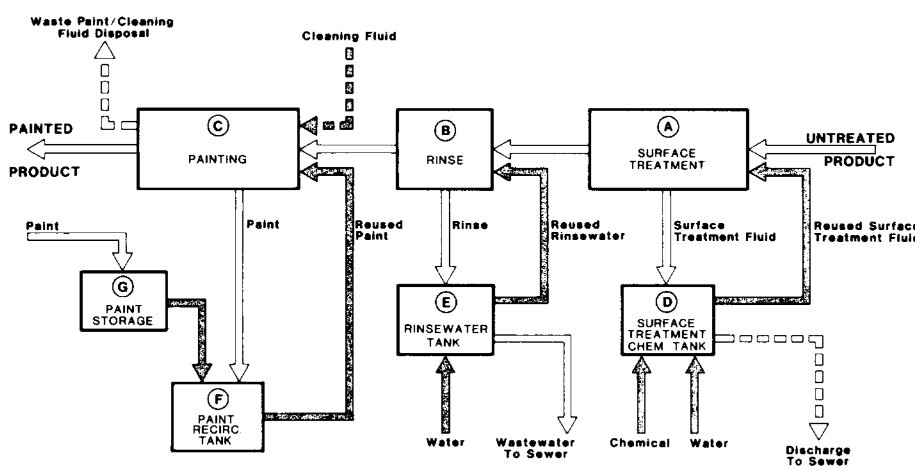
One of the most basic and widely used principles of chemical engineering is that of material balance, i.e., the total weight of what goes into a unit process must equal the total weight of what comes out. The principle of material balance is used later in the waste audit (Phase Four), but it is worthwhile considering the approach at this stage. By obtaining information on inputs and outputs, a material balance can be written around a single item of process equipment, a portion of a process, a complete process or an entire processing plant. It is here that you have to decide on the level of detail you require. As mentioned previously, to begin you may wish to home in on specific problem areas.

It is important to realize, however, that the less detailed the audit, the more information that is likely to be masked or lost. For example, in the process described in Figure 1, Page 15, there are seven unit processes. It is possible to define the inputs and outputs to each unit process, but if time is limited or you consider that the storage tanks are not of specific concern, then effort could be concentrated on the major unit processes, i.e., surface treatment (A), rinsing (B), and painting (C). However, if the surface preparation, rinsing and painting operations were grouped together, information on the loss of water and surface treatment chemicals between the surface treatment stage and the rinse stage could be lost.

By measuring the volume of water and quantity of surface treatment chemicals that are carried over to the rinsing stage you can identify significant raw material losses with subsequent reduction in rinsing efficiency and contamination of the discharge to the sewer. Deciding on the level of detail and homing in on specific areas is therefore very important at an early stage.

In Phase Two of the waste audit the inputs need to be quantified. Step 3 deals with raw materials, chemicals and power, Step 4 with identification of raw material losses, Step 5 with water usage and Step 6 with current levels of waste reuse.

Phase Two: Defining process inputs



Step 3: Determining resource usage

Now that all the unit processes are designated and the interconnections are established, begin to account for material flows to each process at the level of detail you have decided to use. Process inputs should include raw materials, chemicals, process water, steam, and power (to be used for cost/benefit analysis). This study usually begins by examining the purchasing records of raw materials used in the plant.

Assign quantities of raw materials used in each unit process. If accurate information about raw material consumption rates for individual unit processes cannot be obtained from purchasing records, then measurements will have to be made. This should be done over a sufficient period of time to smooth out fluctuations and then be extrapolated for a monthly or annual figure. Attention to detail and thoroughness is essential at the beginning of the audit to accurately assess waste reduction opportunities. Process input data should be recorded on your flow diagram or in a table like Table 2.

Table 2: Annual usage of raw materials

Unit Process	*Raw Material 1 (m^3/yr)*	*Raw Material 2 (tonnes/yr)*	*Raw Material 3 (tonnes/yr)*	*Raw Material 4 (tonnes/yr)*
Surface Treatment (A)	Water	Metal Products	Surface Treatment Chemical	-
Rinse (B)	Water	Metal Products	-	-
Painting (C)	Water	Metal Products	-	Paint
Total Raw Material Used in All Unit Processes				

The waste audit supervisor should be familiar with the various unit processes and should be questioning and developing ideas for improvements. Informal discussions between the waste audit supervisor and the plant operators can yield useful information about what has gone on in the past, what goes on in the present, and why certain things are being done.

Although inputs are treated separately from outputs in this audit, they are closely related when your plant is operating in a steady state mode. Therefore, it is important to measure the outputs relative to the appropriate time as measuring inputs by taking into consideration any significant unit process retention time. This means that the steps outlined in phase 3 need to be carried out in concert with the steps outlined in phase 2.

Step 4: Investigating raw material storage and handling losses

Experience indicates that large amounts of waste can be generated before the actual production process begins. Often, significant quantities of raw materials are lost during storage or material handling. These losses can be quantified as the difference between the total amount of purchased material and the total used in production. You can identify these losses by developing a table like Table 3.

Table 3: Raw material storage and handling losses

Raw Material	*Quantity of Raw Material Purchased (per annum)*	*Quantity of Raw Material Used In Production (per annum)*	*Type of Storage**	*Average Length of Storage*	*Estimated Annual Raw Material Losses*
Raw Material 1 (Surface treatment chemical)	100 kg	95 kg	warehouse	1 month	5 kg
Raw Material 2					
Raw Material 3					

*For example, open vs. closed.

Make notes regarding raw material storage and material handling practices. Consider such things as evaporation losses, spills, leaks from underground storage tanks, vapour losses through storage tank pressure relief vents and contamination of raw materials. Find out reasons for on-site spillage. Purchasing practices should be re-evaluated if high raw material inventories result in spoilage.

Step 5: Recording water usage

Large quantities of water are frequently used in production for cooling, gas scrubbing, clean-ups, product washing and rinsing. Record water usages on the process flow diagram or in Table 4. Water which is not directly used in the processing operations and which is not contaminated during processing can sometimes be left out of the waste audits, although excess water use and the effect on sewer surcharges should be considered. Similarly you may wish to consider steam only when it is consumed in the process.

Table 4: Water usage

Water Use	Process Used	Process Reused	Cleaning Used	Cleaning Reused	Steam Used	Steam Reused	Cooling Used	Cooling Reused	Other Used	Other Reused
Unit Process A										
Unit Process B										
Unit Process C										

Used: Quantity of water used in unit process
Reused: Quantity of water recirculated
All measurements in standard units, e.g. m^3/annum

Tighter control of water use can reduce the volume of waste requiring treatment and result in overall cost savings. Attention to housekeeping practices can often reduce water usage and thus the amount of waste requiring treatment. The cost of storing clean-up waters for later reuse may be far less than the cost of treatment and disposal. Counter-current rinsing and rinsewater reuse will be highlighted in the case studies in Chapter 3. Water usage can be estimated through properly calibrated metering or measurement at the point of use, as necessary. Identify the number of times per day clean-up is undertaken and evaluate the appropriateness of these practices. What controls are placed on indiscriminate water use?

Using less water can have even greater cost savings than the actual cost of water. By reducing the amount of water, through devices like flow restriction valves, waste treatment systems can operate more effectively and be sized smaller. If your wastewaters are metered and your sewer costs based on the quantity of effluent, then these costs are also reduced.

Step 6: Measuring current levels of internal reuse or recycling

Some wastes lend themselves to direct reuse in production. Others may require some level of treatment or modification for reuse as a raw material. In addition, some wastes can be recycled through waste exchanges (see Chapter 4), and may even generate profits or offset costs if sold to another company. These reused materials should be quantified. Estimate the annual quantities of reused materials as a production raw material and record the quantities on your process flow diagram or in Table 5.

Table 5: Annual quantity of reused materials

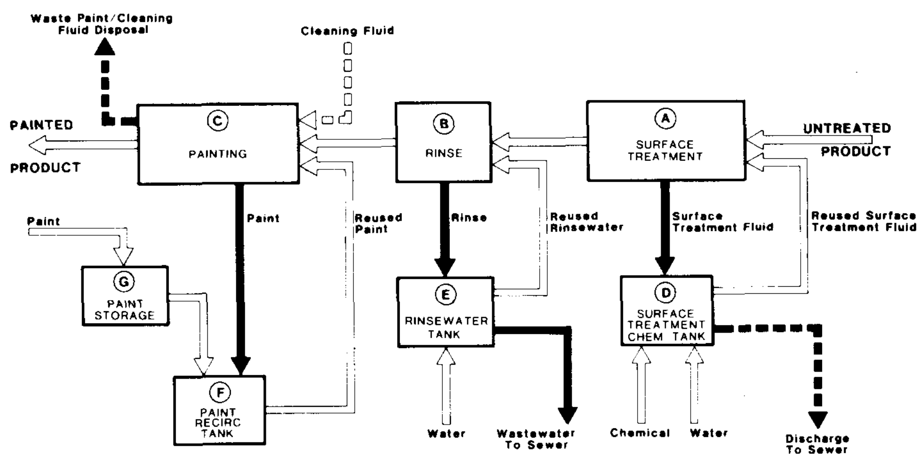
Unit Process	*Material Type*	*Site and Quantity of Waste Reuse (m^3/annum)*	*Material Type*	*Site and Quantity of Waste Reuse (m^3/annum)*
Surface Treatment (A)	Surface Treatment Chemical	Surface Treatment Chamber 12 000 m^3/yr	-	-
Unit Process B (etc.)				
Unit Process C (etc.)				

e.g. Waste Type X could be contaminated rinsewater used as make-up in Unit Process A

The reuse of materials can be facilitated by segregation. Mixing waste streams often compounds problems, sometimes rendering generally non-hazardous waste as hazardous, i.e. by combining a non-hazardous waste stream with a hazardous waste stream you generate a hazardous waste stream of greater volume. Review waste collection and storage approaches to determine if waste segregation is possible.

In Phase Three of the waste audit the outputs from the unit processes need to be quantified. Step 7 deals with the overall output picture, Steps 8 and 9 specify the waste-water flows and wastes hauled off-site.

Phase Three: Defining process outputs



Step 7: Quantifying process outputs

The previous steps should have documented all process inputs as either resources (including power) or reused materials. Now it is necessary to identify and quantify the outputs as primary products, co-products, waste to be reused and waste to be disposed of. The end product output quantities can probably be determined from company records but should also be measured. In the case of intermediary products, measurements, samples and analyses will have to be made. Be sure to identify the units of measurement. Record your process outputs in your process flow diagram or in a table like Table 6. Steps 8 and 9 will assist you in assembling the output information.

Table 6: Process outputs

	Process Outputs					
Unit Process	*Product A*	*Product B*	*Waste to be Reused*	*Wastewater to be Sewered*	*Waste to be Stored*	*Waste to be Disposed of*
Unit Process A						
Unit Process B						
Unit Process C						
Total						

Note: Examples are included in Chapter 3.

Step 8: Accounting for wastewater flows and concentrations

If your plant is like many others, significant quantities of both clean and contaminated water are discharged to the sewer. This costly practice has the potential for undesirable environmental effects and could result in liability to your company. For these reasons, Step 8 is very important to the waste audit and to your company's operation.

Wastewater flows are accounted for along with the concentration of contaminants of concern. Contaminants of concern are defined by the scope of the audit. If you are an electroplater, for instance, you might wish to consider nickel and chromium as contaminants of concern in order to determine how much money is being lost in wastes discharged to the sewer or trucked to disposal. A substance is also definitely a contaminant of concern if it is being discharged in concentrations exceeding regulatory limits. If you do not have in-house analytical facilities, reputable contract laboratories should be contacted for this purpose.

Plan your sampling program thoroughly and try to take samples over a range of plant operating conditions, (e.g. full production, start-up, shutdown and clean-up). The program to collect data should be carried on until there is enough information to allow you to assess existing conditions.

Composite samples should be taken for continuously running wastewater streams (i.e. collection of a small volume, say 100 mL, every hour through a production period, say 10 hours, to get a litre composite sample). The composite sample represents the average wastewater conditions in that timespan. For batch tanks and periodic dumping, a single grab sample may be adequate although periodic sampling of one batch and from batch to batch can highlight operating variations.

Advice on sampling techniques can be obtained from OWMC, environmental consultants or a contract laboratory. A summary of these techniques is provided in Appendix A – Sampling for a Waste Audit. For a more detailed look at sampling, OWMC has published a guide entitled, "Practical Guide for Sampling Wastes and Industrial Processes."

The quantity of the wastewaters generated from each unit process (sewered, stored, reused, discharged to the atmosphere and disposed of) should closely approximate the amount of water metered into the plant. It should be noted that "double counting" can occur where wastewater is reused. This emphasizes the importance of understanding your processes and their interrelationships. Record wastewater flows and concentrations of contaminants of concern in your process diagram or in a table like Table 7.

Table 7: Wastewater flows (for each contaminant of concern)

Source of Wastewater	*Discharge to* *Sanitary Sewers*		*Stormwater*		*Watercourse*		*Reuse*		*Storage*		*Total Wastewater Output*	
	Flow	*Conc'n*	*Flow*	*Conc'n*	*Flow*	*Conc'n*	*Flow*	*Conc'n*	*Flow*	*Conc'n*	*Flow*	*Conc'n*
Unit Process A												
Unit Process B												
Unit Process C												

Flows in m^3/d Concentrations of contaminants of concern in mg/L

Measuring wastewater flows can be relatively simple if your system is metered. However, ensure the meters are accurate and implement a regular calibration check to maintain accuracy. If flows are not metered, then measure flows manually or analyze pumping times and rates. Record these measurements over a sufficiently long period of time and update regularly. One factor that is often overlooked is the use of several discharge points. It is important to identify the location, type and size of all discharge flows. Determine where the discharge usually goes (i.e. sanitary or storm sewer or direct discharge to a watercourse). For this purpose it could be very beneficial to construct a process flow sheet to relate the layout of the process drains and their interconnections. This type of evaluation has often led to startling discoveries about how much waste is inadequately managed.

Step 9: Documenting wastes stored and hauled off-site for disposal

Measure the quantity of solids, sludges and liquid wastes hauled off-site for treatment and/or disposal and record these quantities, and the concentrations of contaminants of concern, on your process flow diagram and/or in Table 8. The MOEE manifest records may be useful here if the waste is defined as a "registerable industrial waste" or a "hazardous waste". According to Regulation 347, all waste generators in Ontario are required to register with the MOEE the types and quantities of liquid industrial and hazardous (solid and liquid) wastes produced. Each time a shipment of these wastes is hauled off-site, a manifest form must be written up according to MOEE requirements. The waste generator keeps one copy of these manifests and from these it is possible to calculate the quantities of hazardous waste generated.

Table 8: Quantities of wastes hauled off-site for disposal
(Similar table for quantities of wastes stored on-site)

	Non-Registerable Wastes					*Registerable Wastes*				
	Solids			*Liquids*		*Solids*			*Liquids*	
Waste	*Qty*	*Conc'n of Cont. #1*	*Conc'n of Cont. #2*	*Qty*	*Conc'n of Cont. #3*	*Qty*	*Conc'n of Cont. #4*	*Conc'n of Cont. #5*	*Qty*	*Con'n of Cont. #6*
Waste A										
Waste B										
Waste C										

All quantities in tonnes/annum
Concentrations of contaminants of concern in grams contaminant/kg waste or in mg/L

We have now investigated and described what goes into the production processes and what has come out of these processes. As described earlier, one of the basic laws of chemical engineering is that the total of what goes into a system must equal the total of what comes out. Therefore, the next stage is to compare the inputs to your production process with the outputs.

When totalling these wastes, take a look at whether any hazardous and non-hazardous waste streams are combined. Review invoices for non-registerable wastes that are hauled by a commercial contractor. Again, take samples of wastes that are hauled away and conduct analyses to determine the wastes' constituents.

Phase Four: The material balance study

This procedure is designed to identify areas where information is inaccurate or lacking. For example, if the total input to a given process for material X is 100 kg and only 50 kg is accounted for in the process output, either the output and/or the input data is inaccurate or the output data is incomplete. This stage is termed the material balance investigation. Where data is deficient, revisiting the situation is required. Keep in mind that it could take a while before *all* raw material and waste flows are accounted for. The waste audit attempts to capture a complete picture at one moment in time. There is usually room for improvement. Furthermore it must be emphasized that it will be almost impossible in most cases to derive a perfect mass balance—a balance to within 10 percent (e.g. Inputs/Outputs x 100 = 90 - 110%) would be deemed very satisfactory in most circumstances.

Step 10: Assembling unit process input and output information

Begin the material balance by developing standard units of measurement (litres, tonnes or kilograms) on a per day, per year or per batch basis. This is the only practical way that a balance for the whole plant, or a unit process, can be carried out.

Summarize the measured values in standard units in schematic form by utilizing your process flow diagram (Figure 1). Note: modifications might be needed to Figure 1 following your work in the plant. The inputs and outputs can also be listed in tabular form as in Table 9.

Table 9: Inputs and outputs of unit processes

Unit Process A	
Inputs	**(amounts in standard units per annum)**
Raw material A	
Raw material B	
Raw material C	
Material reuse	
Water	
Outputs	(amounts in standard units per annum)
Manufactured product	
Raw material handling and storage losses	
Reuseable materials	
Atmospheric emissions	
Sewered waste (excluding water)	
Non-hazardous liquid waste D hauled off-site	
Hazardous liquid waste E hauled off-site	
Non-hazardous solid waste F hauled off-site	
Hazardous solid waste G hauled off-site	
Water	

Step 11: Deriving a preliminary material balance for unit processes

Now it is possible to complete a preliminary material balance. For each unit process utilize the data developed in Steps 1 through 9 and construct your material balance. Use the process flow diagram to construct a graphical material balance. You might also find it useful to tabulate your input and output information as in Figure 2.

Figure 2: Preliminary material balance for unit processes

Inputs (amounts in standard units per annum)

Raw material A
Raw material B
Raw material C
Material reuse
Water
Total

▼

Unit Process A

▼

Outputs (amounts in standard units per annum)

Manufactured product
Raw material handling and storage losses
Reused material
Atmospheric emissions
Sewered waste (excluding water)
Non-hazardous liquid waste D hauled off-site
Hazardous liquid waste E hauled off-site
Non-hazardous solid waste F hauled off-site
Hazardous solid waste G hauled off-site
Water
Total

Once the material balance for each unit process has been completed for the total amount of raw material inputs and waste outputs it might be necessary to repeat them with respect to each contaminant of concern as in Figure 3. Material balances for individual contaminants should be done for those contaminants which pose a specific problem in costs, environmental impact, or health and safety. Figure 3 might have to be modified in the event that a contaminant of concern is emitted to the atmosphere, or if one is formed as a result of a chemical reaction in the unit process.

It is highly desirable to carry out a water balance to account for all water inputs and outputs to and from unit processes because water imbalances could indicate serious underlying process problems such as leaks or spills.

Figure 3: Preliminary material balance for a contaminant of concern in Unit process A

Inputs (amounts in standard units per annum)

Amount of contaminant of concern contained in raw material A
Amount of contaminant of concern contained in raw material B
Amount of contaminant of concern contained in raw material C
Amount of contaminant of concern in reused waste
Total amount of contaminant of concern

▼

Unit Process A

▼

Outputs (amounts in standard units per annum)

Amount of contaminant of concern in manufactured product
Amount of contaminant of concern wasted in handling and storage losses
Amount of contaminant of concern in material to be reused
Amount of contaminant of concern in sewered waste
Amount of contaminant of concern in non-hazardous liquid waste D hauled off-site
Amount of contaminant of concern in hazardous liquid waste E hauled off-site
Amount of contaminant of concern in non-hazardous solid waste F hauled off-site
Amount of contaminant of concern in hazardous solid waste G hauled off-site
Total amount of contaminant of concern

Step 12: Evaluating the material imbalance

Whether you have a material imbalance or not, the individual and sum totals making up the material balance should be reviewed to determine assumptions, information gaps or inaccuracies. If you do have a significant material imbalance then further investigation is needed. For example, if outputs are less than inputs, then look for obvious sources of loss or waste discharges (e.g. evaporation).

It is also possible for outputs to apparently be greater than inputs if large measurement or estimating errors are made or some inputs are not accounted for. Even if the equation appears to balance, you should take the time to examine where unnoticed losses may be occurring. It might be necessary to repeat some of your information gathering activities. Remember that you need to be thorough and consistent in order to obtain a satisfactory material balance. The material balance not only reflects the adequacy of your data collection activities, but by its very nature ensures that you have a sound understanding of the processes involved.

Step 13: Refining the material balance

Now you can reconsider the material balance equation by adding previously unaccounted for losses into the output side and any adjustments to the total inputs, and run through another material balance. If necessary, estimates of unaccounted for losses will have to be calculated. Remember, ideally the inputs should equal the outputs. In practice, however, this will rarely be the case and some judgement will be required to determine what accuracy is acceptable. In the case of high strength and hazardous wastes accurate measurements should be obtained for the waste reduction studies.

The material balance approach should be performed at the level of detail you decided to conduct the study. You may need to repeat the material balance for a number of the unit processes identified in Steps 1 to 9 as well as an entire production area. Again, continually review, refine and, where necessary, expand your database. The compilation of accurate, comprehensive data is essential to your successful waste audit and subsequent waste reduction.

Phases 1 to 4 have been involved with developing the waste audit for your plant. Phase 5 now looks at using the information obtained to identify waste reduction alternatives.

Phase Five: Identifying waste reduction alternatives

Step 14: Examining obvious waste reduction measures

Now that your waste audit has been essentially completed, it is time to look into implementing waste reduction measures, some of which probably became obvious during the studies. You should adopt and maintain a definite waste prevention program by developing a code of good operating practice. For example:

- Plug leaks and fit flow restrictors to try to reduce water consumption.
- Implement a thorough and satisfactory maintenance program to prevent leaks.
- Install level controls to prevent overflows.
- Attempt to reuse washwaters and rinsewaters.
- Install adequate storage capacity to prevent overflows.
- Install tanks to hold wastewaters for reuse.
- Install tanks that are, or can be, pitched and elevated from the floor and that have well rounded corners for ease of drainage and rinsing.
- Determine whether or not your wastes can be separated "clean" from "dirty" or "aqueous" from "organic". If this is done, then concentrate on material recovery from the "dirty" wastewater.
- Find out if hazardous wastes can be segregated from non-hazardous wastes and implement segregation where possible.
- Find out if solid wastes can be segregated from aqueous waste streams and implement segregation where possible.
- Consider reusing scraps of material.
- Study your plant processes and review for potential to install technologies which generate less waste.
- Investigate the listing of your wastes on the Ontario Waste Exchange. Other plants might be able to recycle your wastes in their processes.

Step 15: Targeting and characterizing problem waste streams

Having gone through Steps 1 to 14, you will have identified all your problem areas and begun to consider them for waste reduction, reuse and recycling (the 3Rs). Obvious waste reduction measures were identified in step 14. However, you may find it necessary to focus attention on "problem" waste streams that are:

- costly to dispose of
- generated from expensive raw materials
- causing treatment problems
- classified as hazardous under government regulations.

Even though wastes were analyzed for contaminants of concern in Steps 8 and 9, additional sampling and characterization of your wastes might be necessary for problem streams that are difficult to reduce, reuse, recycle or treat. An example of a "problem" waste is described in Case Study 1. In this instance a detailed characterization determined the presence of chelating agents in a copper containing wastewater. These agents prevented copper removal by conventional metal hydroxide precipitation. The study concluded that an ion-exchange/electrolytic recovery system was needed to treat this wastewater.

Another company decided to undertake a detailed characterization of its wastes when it had problems disposing of spent pickle liquor. After taking a closer look, the company opted to crystallize iron sulfate out of solution and recycle the residual pickle liquor by adding fresh acid. This solution is highlighted in Case Study 2.

Treatability studies determine optimum treatment requirements and can help improve present treatment methods. Some water treatment chemical suppliers and environmental consultants can do treatability testing for you and there are some equipment suppliers who can run laboratory and pilot tests to determine optimum conditions for treatment and recovery. The resources and information in Chapter 4 describe additional options that are available.

Step 16: Developing long term waste reduction alternatives

Longer term waste reduction alternatives will require the evaluation of potential process/production changes, waste separation, reuse, and/or treatment technologies. Potential process/production changes which may increase production efficiency and reduce waste generation include:

- continuous versus batch production
- process retention times, temperatures, agitation, pressure, catalysts, etc.
- use of dispersants in place of organic solvents
- changes in the quantities or types of raw materials
- raw material substitution through the reuse of materials or the use of raw materials that result in either less waste or less hazardous wastes.

Waste reuse can often be easily implemented if materials are of a sufficient purity. Other wastes can be concentrated or purified. Technologies such as reverse osmosis, ultrafiltration, electrodialysis, distillation, electrolysis and ion exchange may enable materials to be reused and thus reduce or eliminate the need for waste treatment.

Where waste treatment is necessary, a variety of technologies should also be considered. These include physical, chemical and biological treatment processes. In some cases the treatment method can also recycle valuable materials for reuse. Chapter 4 describes how you can get further information relating to recycle, reuse, treatment and associated technologies. Once the potential opportunities for waste reduction and reuse have been identified, smaller companies may wish to bring in a reputable environmental consultant with the technical expertise to evaluate the various technologies.

Phase Six: Cost/ benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction

From Step 16, a number of waste minimization and treatment alternatives have been identified which may have widely differing effects on the process. Long term alternatives may include:

- process related changes (e.g. acid recycling for steel pickling)
- technology for treating and recycling specific waste streams (e.g. ion exchange or electrolytic metal recovery)
- implementation of technology for end-of-pipe treatment (e.g. biological treatment of combined chemical wastewaters)

Although the cases studies represent different circumstances, the general procedure for conducting cost/benefit analysis is the same. It involves an analysis of present production costs including waste disposal and treatment costs. Next, an analysis of the full costs of alternative processes is done and finally a cost/benefit comparison. The approach described below is generic. There are numerous methods for conducting cost evaluations.

a) Present production cost analysis

The annual operating costs for the existing production and treatment system can be evaluated as in Table 10.

Table 10: Present production costs (including waste disposal and treatment costs)

Item	*Annual Cost ($)*
Labour	______
Utilities	______
Raw materials	______
Waste disposal	
Hazardous waste	______
Non-hazardous waste	______
Wastewater costs	
Treatment chemicals	______
Sewer (surcharge and fees)	______
Maintenance	______
Administrative cost (e.g. supervision, regulatory response)	______
By-product credit	______
Total Annual Production Cost	______

b) Determination of cost (and benefits) of each waste treatment/reduction alternative

The operating costs of each waste treatment/reduction alternative is then determined in the same manner as Table 10 above.

Information for the costing study can be obtained from equipment suppliers and possibly from reference material (see Chapter 4).

c) Cost/benefit comparison of present and alternative treatment/reduction technologies

In cases where the total annual operating cost of an alternative treatment/reduction technology is lower than the total annual operating cost of the current production and waste treatment system, a study should be undertaken to determine whether this net benefit is sufficient to pay for the cost of implementing the alternative method. Each company has its own criteria for conducting this evaluation. Discounted cash flow analysis is one commonly used method.

The cost/benefit approach used to evaluate alternative treatment/reduction technologies is based solely on economics. While the economic factor is generally the main motivation for companies to adopt waste reduction alternatives, there are cases in which other factors can override short-term economic costs associated with waste reduction. For example, infringements of environmental or occupational health regulations could result in heavy fines or even in a court injunction to shut down the polluting company.

Sometimes the benefits are intangible, such as creating a cleaner, healthier workplace with increased employee morale and reduced absenteeism. The public relations value of implementing waste reduction measures likewise should not be overlooked. It could also turn out that the alternative waste reduction technology will simultaneously improve the quality of the final product and result in increased sales. The fact that such intangible benefits are difficult to quantify from a monetary point of view does not diminish their potential contribution to the overall success of your operation.

The case studies in Chapter 3 give different examples of cost/benefit analyses.

Step 18: Implementing your action plan: reducing wastes and increasing production efficiency

It takes time for plant personnel to feel comfortable with a new way of thinking. Therefore, it is a good idea to allow everyone time to adapt to these changes by implementing waste reduction approaches slowly but consistently.

Costs associated with waste management should be charged to the production units generating these wastes. This will encourage production personnel to reduce their operating costs by adopting waste reduction alternatives.

You have now completed the important first step in the waste audit/ waste reduction study and have amassed a wealth of information and no doubt increased your knowledge of the plant. It is now time to review what has been done and to develop an action plan. To prepare for this stage it is helpful to answer the following questions:

- Did the exercise highlight areas of inefficiency and enable you to improve production efficiency and waste management approaches and costs? Quantify your successes.

- Is outside expertise or additional manpower required to complete the audit or undertake further work? If so, consult Chapter 4 or enquire about reputable consulting services.

- Are the costs of implementation too high? If so, consult the sources of public funding discussed in Chapter 4. Can implementation be done in stages?

- Have you highlighted significant information gaps or inconsistencies? If so, concentrate on these areas and explore ways and means of developing additional data. Is outside expertise required? Again, see Chapter 4.

- Discuss your findings and solicit ideas from other staff. Utilize in-house expertise first.

- Attempt to develop a specific waste audit/waste reduction approach for your plant. Discuss this approach with similar industry people who may have undertaken a plant waste assessment or are about to do so.

- Consider all possible resources. If you are looking for further information, call the Waste Reduction personnel at Ontario Waste Management Corporation (416) 923-2918 or 1-800-268-1178 (toll free).

Chapter 3: Case Studies

In this chapter the application of the waste audit/waste reduction approach is described in three case studies. Each of these studies has been developed from different examples of industrial waste reduction in Ontario.

Case study 1: Printed circuit board manufacturing

Company A manufactures double-sided and multi-layered circuit boards for the telecommunications and computer markets in North America and Europe. The manufacturing of printed circuit boards involves a complex series of physical and chemical processing stages and as a result the wastewaters which are generated are complex, of variable composition and difficult to treat. To compound the treatment problems, many of the processing solutions contain proprietary chemicals whose composition is not available.

The main pollutants in printed circuit board manufacturing wastewaters are heavy metals, particularly copper. Company A's wastewater effluent frequently exceeds the local municipal by-laws which control discharges to the municipal sewer system. Although the company has implemented some improvements to its wastewater treatment system in recent years, discharges in excess of the by-law standard of 5 mg/L of copper continued to occur and the municipality eventually decided to take legal action against Company A for persistent violation of discharge standards.

In response to these problems, the company decided to conduct a waste audit, using the Waste Audit and Reduction Manual, in order to:

- identify the sources of contamination
- develop a waste reduction strategy to minimize contaminants at source
- develop a sound understanding of the wastewater problems to facilitate the design of a cost-effective wastewater treatment system

Because of the complexity of the printed circuit board manufacturing plant it is worthwhile at this stage to give a brief description of the major processing steps. The board material is composed of a glass fibre sheet that is copper laminated on both sides. The uncut boards are received from the suppliers in large sheets and pass through a shearing stage to cut them to the desired size. The boards are then drilled and pass through a surface conditioning stage (deburring) before undergoing a series of treatments in the sensitizing area (electroless plating). This treatment essentially coats copper into the holes and prepares the holes for electroplating.

The next stage involves the application of a photopolymer resist material which masks off areas which do not need to be electroplated. The printed circuit areas are subsequently developed (to remove unexposed resist areas which are to be plated) and pass through microetching, copper electroplating, solder electroplating, resist stripping, copper etching and a number of other selected finishing treatments as specified by the customer. The final stages of manufacture involve final fabrication and electrical testing.

The printed circuit board manufacturing plant is complex and a great number of different process wastes are thereby generated. The following case study describes the approach taken to overcome the long-standing waste treatment problems encountered by Company A. The investigations were based on the Waste Audit and Reduction Manual and the studies highlighted a number of areas where processing and treatment efficiencies could be improved.

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes

Step 1 of the waste audit involved walking around the entire printed circuit board manufacturing plant in order to gain a sound understanding of all the processing operations and their interrelationships. It was important from the outset to determine what level of detail was required for the study. Due to the complex nature of the printed circuit board plant it was not considered appropriate to list all the unit processes in fine detail. Instead, the plant was broken up into processing areas. Furthermore, as copper was by far the major contaminant of concern, it was decided at this stage to conduct the waste audit with specific reference to copper.

Figure 1 shows the general schematic process flow diagram which was constructed from the initial plant investigations. By studying the processing operations, asking questions around the plant and assembling supplier information on chemicals and processes, it was possible to identify the areas in the plant where waste copper was generated. These areas were the:

- deburring operation (sensitizing)
- sensitizing line (electroless plating)
- electroplating line (copper electroplating, solder electroplating, moist strip and copper etch)
- oxide coating area (including oxide deburring, oxide coating, solder stripping and lacquer finishing)

It is important to note that copper was not considered in isolation and that factors which could affect the form and ultimate treatability of copper were also considered (e.g. presence of chelating agents).

Step 2: Constructing process flow diagrams

Once the main processing areas which generated waste copper had been identified the process flow diagrams were constructed for each area. This involved a more detailed study of each processing area and the identification of process inputs and outputs. In addition to the four processing areas mentioned, a process flow diagram of the existing wastewater treatment plant was also developed. Figures 2-6 show the process flow diagrams for these main processing areas. It should be noted that some diagrams are simplified for the purposes of the case study.

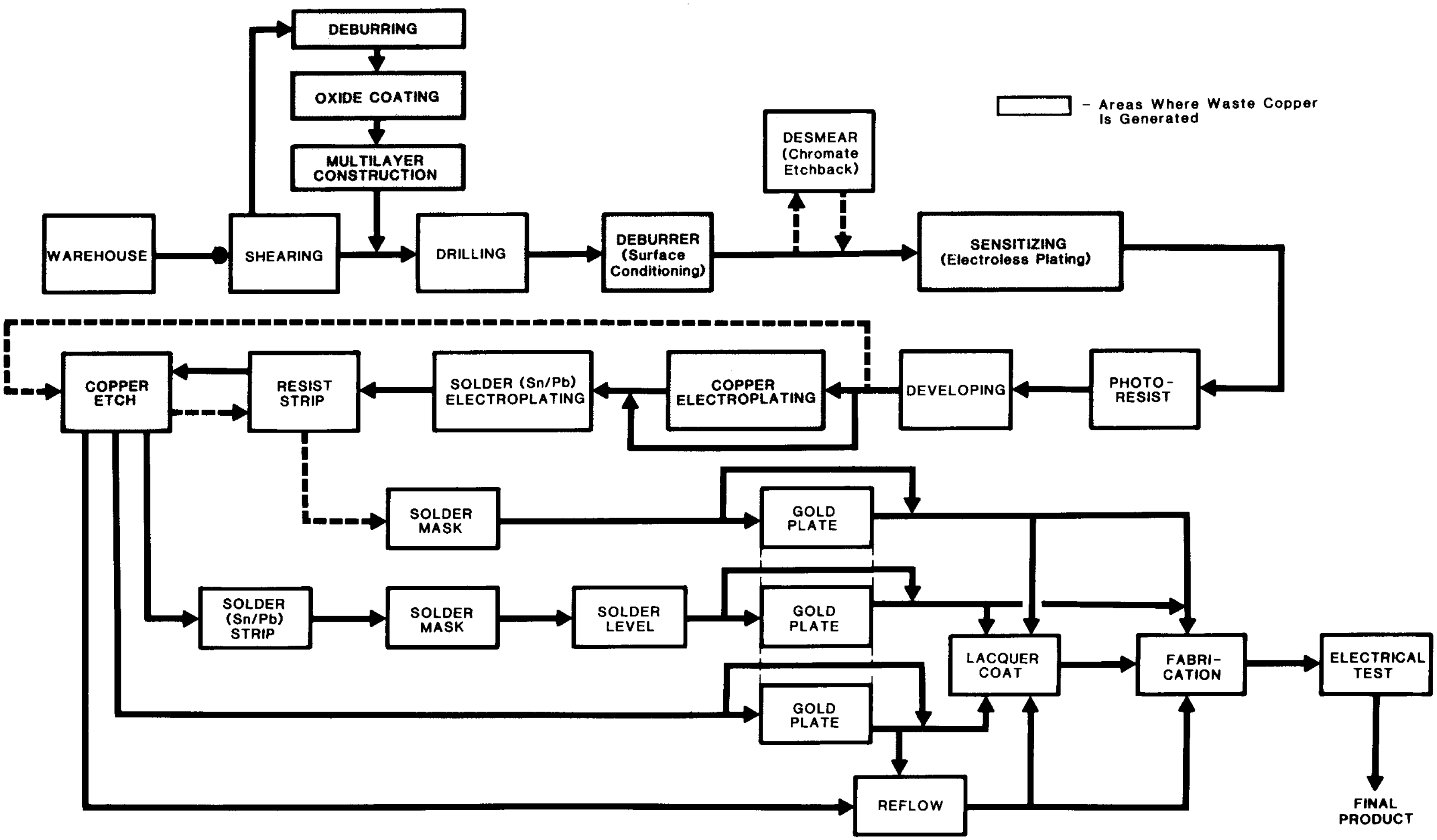


Figure 1: General flow diagram for the printed circuit board manufacturing plant

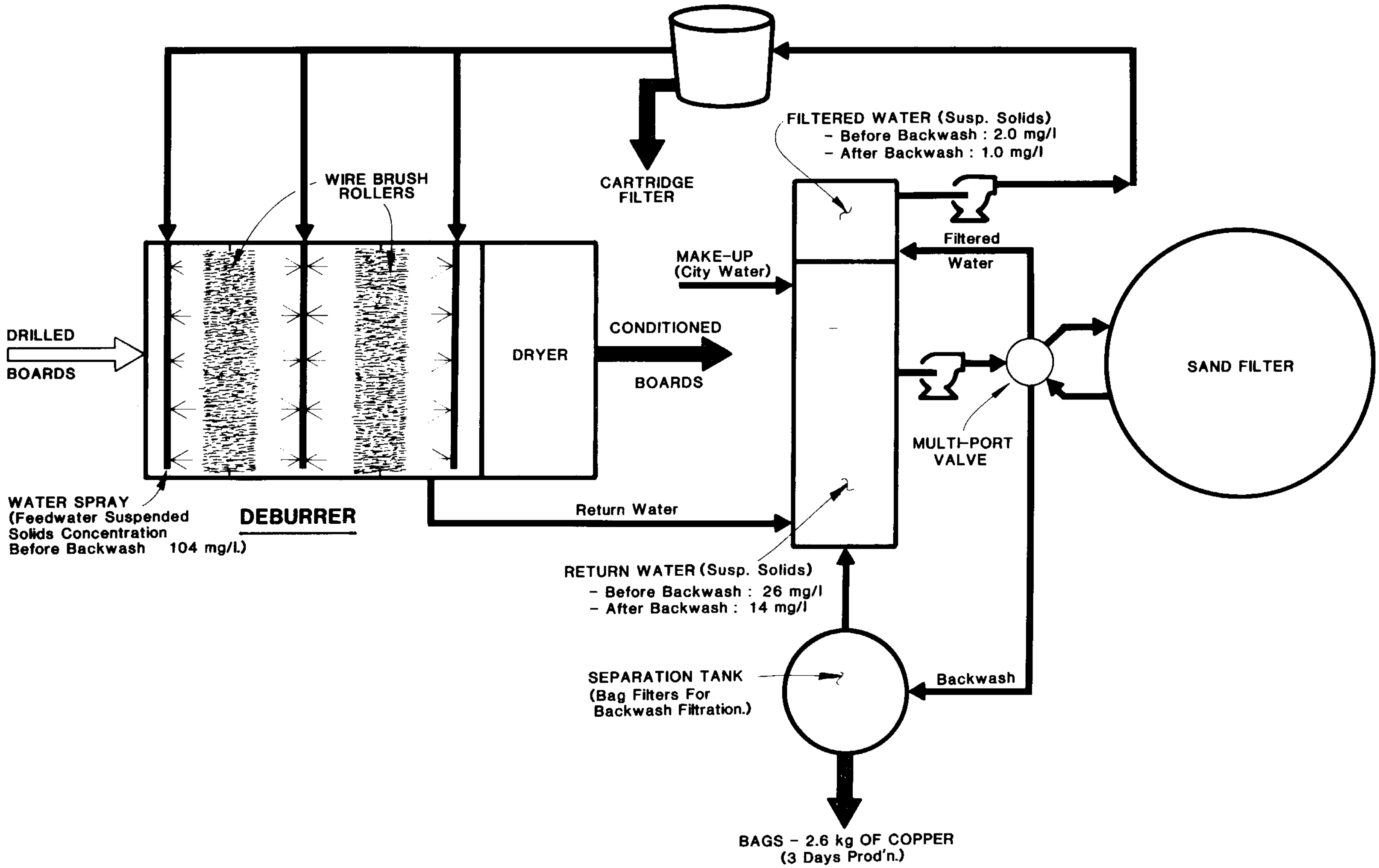
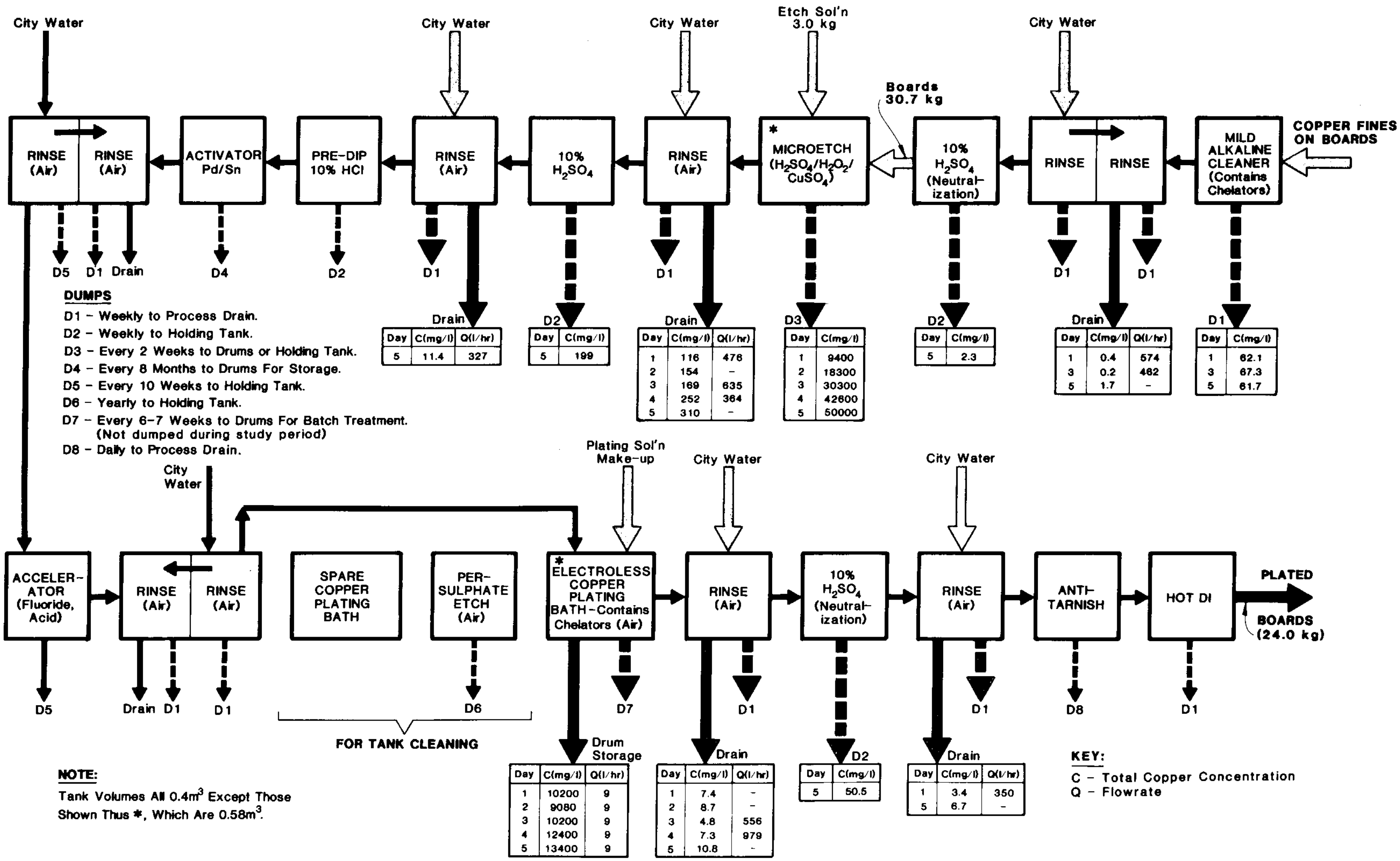


Figure 2: Process flow diagram for sensitizing deburrer



Rinse (Air) after Pre-dip, Drain:

Day	C(mg/l)	Q(l/hr)
5	11.4	327

10% H_2SO_4, D2:

Day	C(mg/l)
5	199

Rinse (Air) after Microetch, Drain:

Day	C(mg/l)	Q(l/hr)
1	116	476
2	154	-
3	169	635
4	252	364
5	310	-

Microetch, D3:

Day	C(mg/l)
1	9400
2	18300
3	30300
4	42600
5	50000

10% H_2SO_4 (Neutralization), D2:

Day	C(mg/l)
5	2.3

Rinse / Rinse, Drain:

Day	C(mg/l)	Q(l/hr)
1	0.4	574
3	0.2	462
5	1.7	-

Mild Alkaline Cleaner, D1:

Day	C(mg/l)
1	62.1
3	67.3
5	61.7

Electroless Copper Plating Bath, Drum Storage:

Day	C(mg/l)	Q(l/hr)
1	10200	9
2	9080	9
3	10200	9
4	12400	9
5	13400	9

Rinse (Air) after Electroless Bath, Drain:

Day	C(mg/l)	Q(l/hr)
1	7.4	-
2	8.7	-
3	4.8	556
4	7.3	979
5	10.8	-

10% H_2SO_4 (Neutralization), D2:

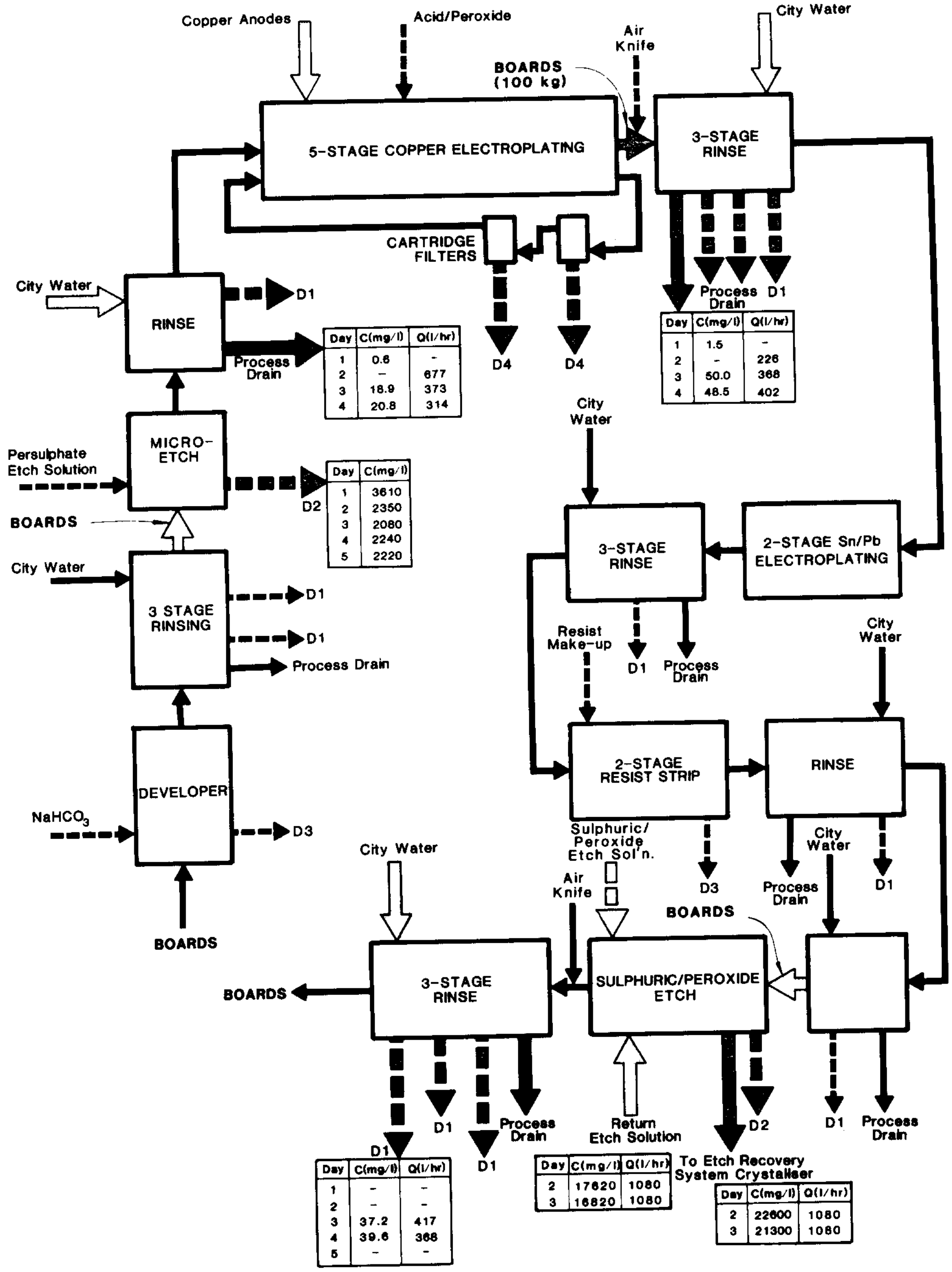
Day	C(mg/l)
5	50.5

Rinse (Air) before Anti-tarnish, Drain:

Day	C(mg/l)	Q(l/hr)
1	3.4	350
5	6.7	-

Figure 3: Process flow diagram for sensitizing (electroless plating) area

Figure 4: Process flow diagram for 9000 line (Cu electroplating Sn/Pb electroplating, resist strip and etching)



Day	C(mg/l)	Q(l/hr)
1	0.6	-
2	–	677
3	18.9	373
4	20.8	314

Day	C(mg/l)
1	3610
2	2350
3	2080
4	2240
5	2220

Day	C(mg/l)	Q(l/hr)
1	1.5	-
2	-	226
3	50.0	368
4	48.5	402

Day	C(mg/l)	Q(l/hr)
1	-	-
2	-	-
3	37.2	417
4	39.6	368
5	-	-

Day	C(mg/l)	Q(l/hr)
2	17620	1080
3	16820	1080

Day	C(mg/l)	Q(l/hr)
2	22600	1080
3	21300	1080

KEY:

C - Total Copper Concentration
Q - Flowrate

DUMPS

D1 - Daily to Process Sewer
D2 - Monthly to Holding Tank
D3 - Daily to Holding Tank
D4 - Change Filters Quarterly

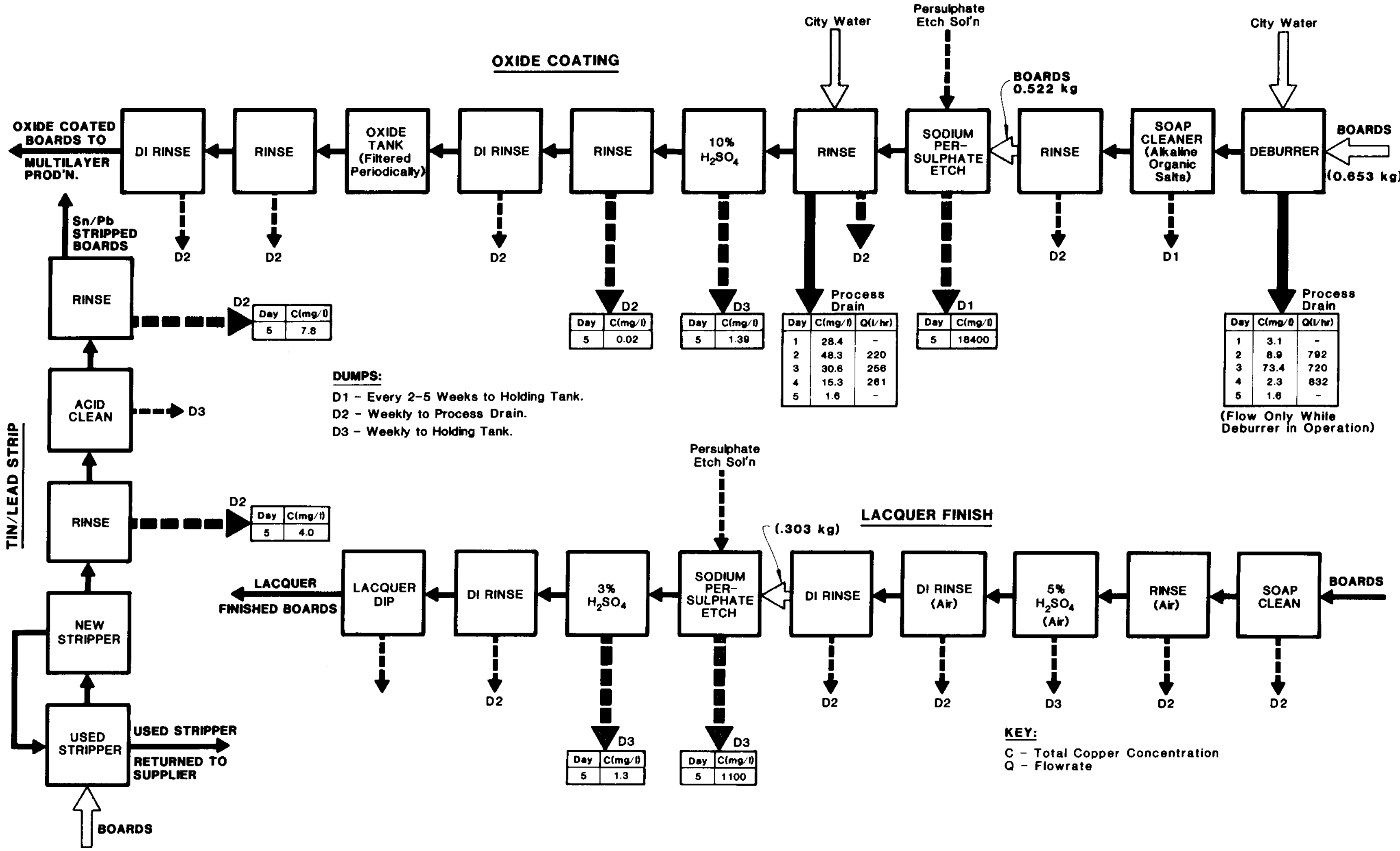
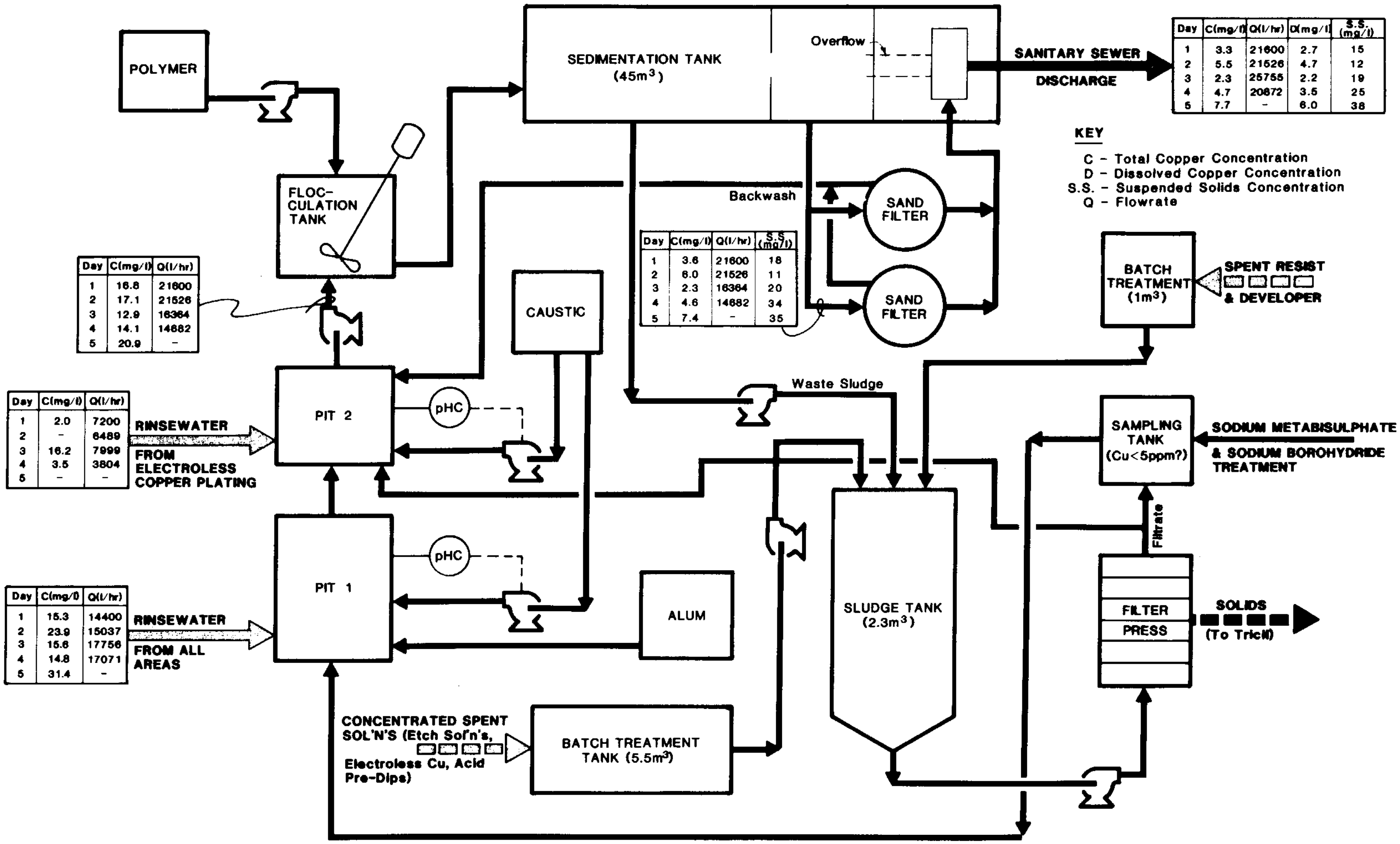


Figure 5: Process flow diagram for oxide coating, lacquer finish and tin/lead strip



Day	C(mg/l)	Q(l/hr)	D(mg/l)	S.S. (mg/l)
1	3.3	21600	2.7	15
2	5.5	21526	4.7	12
3	2.3	25755	2.2	19
4	4.7	20872	3.5	25
5	7.7	-	6.0	38

Day	C(mg/l)	Q(l/hr)	S.S. (mg/l)
1	3.6	21600	18
2	6.0	21526	11
3	2.3	16364	20
4	4.6	14682	34
5	7.4	-	35

Day	C(mg/l)	Q(l/hr)
1	16.8	21600
2	17.1	21526
3	12.9	16364
4	14.1	14682
5	20.9	-

Day	C(mg/l)	Q(l/hr)
1	2.0	7200
2	-	6489
3	16.2	7999
4	3.5	3804
5	-	-

Day	C(mg/l)	Q(l/hr)
1	15.3	14400
2	23.9	15037
3	15.6	17756
4	14.8	17071
5	31.4	-

Figure 6: Process flow diagram for wastewater treatment plant

In Phase One the processes which involved copper were identified and the interconnections between these processes established. In Phases Two and Three the material flows to and from these processes need to be determined by collecting input and output information.

Phase Two: Defining process inputs

Due to the relative complexity of the printed circuit board plant the inputs and outputs for the unit operations were recorded on the process flow diagrams using Steps 3-5 of the waste audit manual. It should be emphasized that the input and output information was collected in the plant simultaneously even though the auditing procedures are described in the manual as discrete steps.

While conducting the in-plant survey and collecting the input and output information the investigating team was noting any areas of inefficient operation and any opportunities for waste reduction. These opportunities are discussed later in Phase Five.

Step 3: Determining resource usage

Input information was obtained from measuring chemical additions and water use and recording the area of copper circuit boards processed (etched*). In the case of the electroplating line the weight of copper anode used (the source of copper for electroplating) was estimated from past data. The wastewater treatment plant inputs were determined by measuring the total wastewater flows and concentrations.

Copper input information for the five processing areas was then recorded on the process flow diagrams in Figures 2-6.

*Etching of the copper circuit boards involves acid treatment for surface conditioning, or finishing, and represents a significant copper input.

Step 4: Investigating raw material storage and handling losses

Due to the nature of the copper raw materials (copper sulphate solutions and copper laminated boards) no handling losses were considered to occur prior to the processing operations.

Step 5: Recording water usage

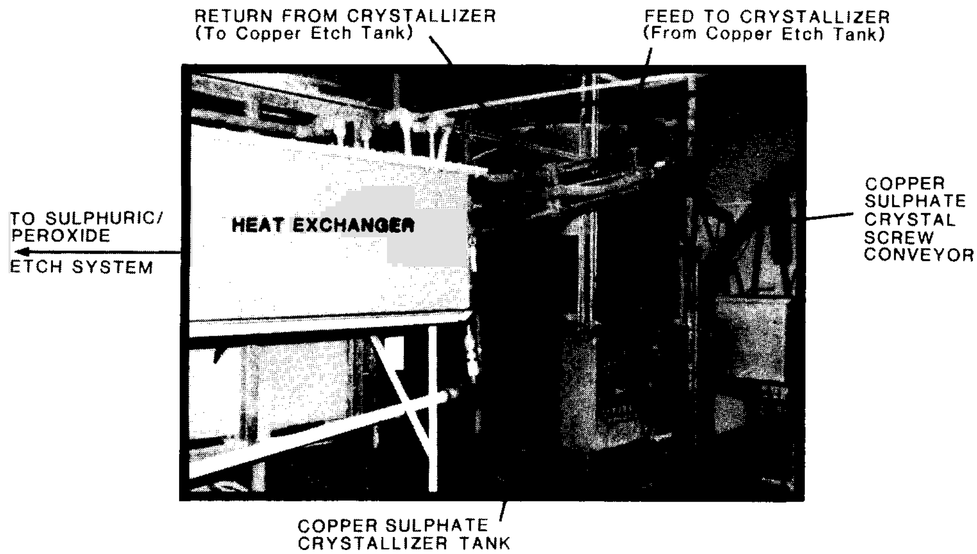
The rinsewater flowrates were measured at the inlet to the rinse tanks by measuring the time to fill a known volume container or by draining down the rinse tanks and measuring the time to refill. Company A had recently installed flow restrictors on the rinsewater feed pipes, a good water conservation measure, in order to limit the amount of water being used in the rinsing operations. In general, the flowrates measured were in accordance with the ratings for the flow restrictors.

The water usage data was also recorded on the process flow diagrams (Figures 3-6).

Step 6: Measuring current levels of waste reuse

Copper-containing wastes were not generally reused at the plant. However, there was an on-line crystallizer on the sulphuric/peroxide etch stage of the electroplating line. The following photo shows the copper sulphate crystallizer and etch solution recovery system. The etch solution is pumped from the etch tank through the heat exchanger and into the copper sulphate crystallizer where the spent etch solution is cooled to 16°C. Copper sulphate crystals are precipitated and then conveyed to the storage bins, drained and subsequently sold to a local plating shop. The recovered etch solution is returned to the etch feed tank. The quantity of etchant reused is described as an input in Figure 4.

Photo: Etch solution recovery and copper crystallization system



Phase Three: Defining process outputs

Step 7: Quantifying process outputs

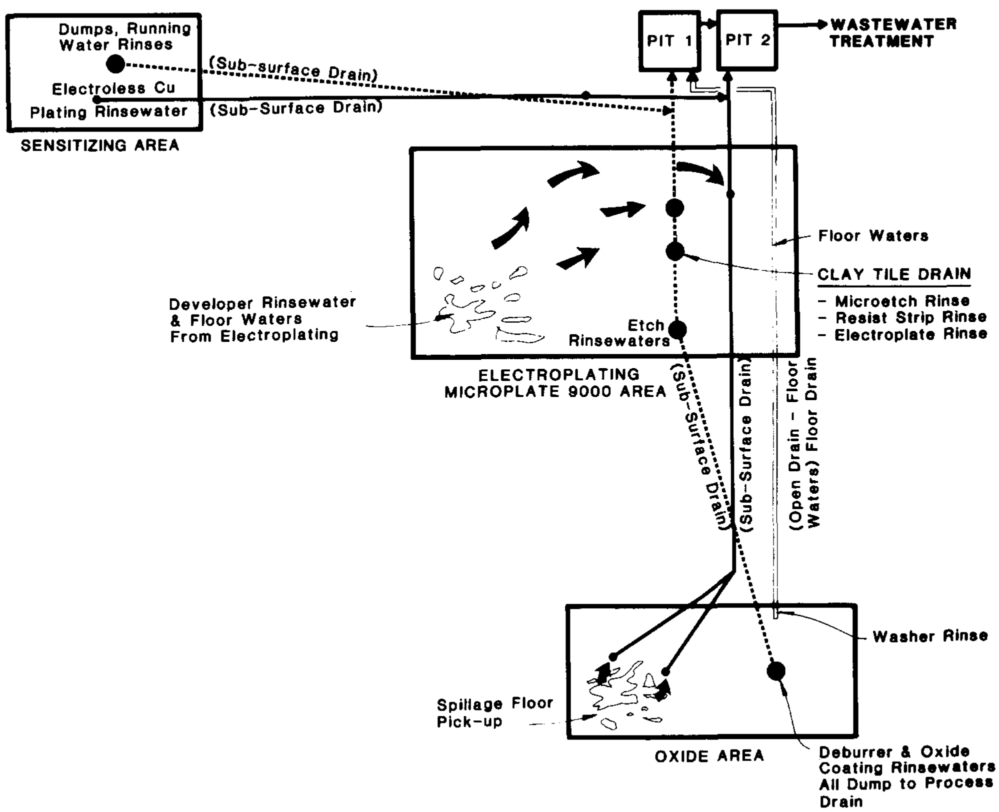
The copper related process outputs were identified and then quantified from copper plating records and the measurement of waste masses, volumes and concentrations. Apart from the quantity of copper plated onto the printed circuit boards, which was determined from production information and plating thickness used, the process output information was obtained from measurements taken in the plant.

Step 8: Accounting for wastewater flows and concentrations

All the wastewater streams which were identified as containing copper (from Steps 1 and 7) were investigated in a thoroughly planned and conceived sampling programme. The sampling was performed over a production week in order to cover the full range of operating conditions and to ensure representative data. Composite samples were taken for all running wastewater streams whereas batch tanks and dumpings were sampled with a grab method. Samples were also taken from the outputs from the wastewater treatment plant. The samples were carefully labelled, logged and sent out to a contract laboratory for copper and supporting analyses. Wastewater flows and tank volumes were also recorded. The wastewater information is described in Figures 2-6.

In addition, a process flow diagram describing the layout of the process drains was constructed (Figure 7). Dye tests were performed to determine the fate of the wastewater streams and the layout and interconnections of the surface drains. These studies highlighted some unnecessary and complex rinsewater piping arrangements which were subsequently modified by plant engineering staff.

Figure 7: Layout of process drains



Step 9: Documenting wastes stored or hauled off-site for disposal

The quantity of waste material stored on-site and hauled off-site for disposal was estimated from in-plant investigations and study of company records. The registerable wastes hauled off-site for disposal included: copper fines (270 g/100 m^2 of board), cartridge filters, and filter press cake (1360 kg/week). The tin lead activator dump (0.7 m^3/annum) was stored on-site as registerable liquid waste.

Phase Four: The material balance study

Step 10: Assembling unit process input and output information

The material balances were started by assembling the complete input and output data, converted to standard units, on the process flow diagrams (Figures 2-6).

Step 11: Deriving a preliminary material balance

From the collated information the preliminary balances were constructed for each processing area.

a) Sensitizing deburrer

The deburrer located in the sensitizing area is operated in a recycle mode (see Figure 2). Return water is continuously filtered to remove copper fines before being fed back to the deburrer. Captured copper fines are subsequently backwashed from the sand filter and collected in the bag filter. Essentially the copper inputs are from the brushed boards and the outputs are from the sand filter backwash bag filter and the cartridge filter. An accurate mass balance could not be constructed from the available information as the thickness of copper removed from the boards could not be determined precisely. However, Company A did plan to purchase a high resolution microscope in the near future which would enable accurate determination and control of copper thicknesses removed.

b) Sensitizing (Electroless Plating)

The preliminary material balance for the electroless plating line is shown below.

Copper Inputs (kg/week)	
Copper fines from deburrer	0.040
Boards (microetch)	30.700
Etch solution	3.000
Electroless plating solution	25.000
Total	58.743

▼

Electroless Plating

▼

Copper Outputs (kg/week)	
Boards (plated)	21.283
Rinsewaters	4.867
Dumps	0.261
Microetch dump	29.000
Electroless copper (storage)	4.400
Total	60.811

c) Electroplating Line (Microplate 9000 line)

Copper Inputs (kg/week)	
Boards (microetch)	0.667
Boards (sulphuric/peroxide etch)	209.586
Copper anodes	124.500
Return etch solution	743.904
Total	1078.657

▼

Microplate 9000 Line

▼

Copper Outputs (kg/week)	
Boards (plated)	100.078
Rinsewaters	1.474
Dumps	0.523
To etch recovery (18 L/min) (including 217.000 kg crystallized copper)	948.240
Total	1050.315

No make-up or dump of the sulphuric acid/peroxide etch tanks was made during the study period and as the crystallizer maintains a constant copper concentration in the etch tank these inputs and outputs were not considered in the material balance study.

d) Oxide coating area

Copper Inputs (kg/week)	
Boards (deburring)	0.653
Boards (microetches 10×10^{-6} inch)	0.825
Total	1.478

▼

Deburrer, Oxide Coating and Lacquer Finish

▼

Copper Outputs (kg/week)	
Rinsewaters	0.195
Dumps (drain)	0.003
Dumps (holding tank)	0.311
Copper fines (to drain)	0.632
Estimated copper increase in oxide Microetch bath	0.347
Total	1.488

e) Water treatment

Copper Inputs (kg/week)	
Pit 1 Influent	12.493
Pit 2 Influent	12.293
*Concentrated spent solutions	1.695
Total	26.481

▼

Water Treatment System

▼

Copper Outputs (kg/week)	
Sanitary sewer discharge	5.239
Filter press sludge (Estimated by difference)	21.242
Total	26.481

*No concentrated copper solutions treated in the study period

The amount of copper disposed of in the filter press sludge was difficult to measure since it was withdrawn from the clarifier on an irregular and infrequent basis. Instead, the copper output in the filter press sludge was estimated by taking the difference of the copper discharged to the sanitary sewer subtracted from the copper in the pit influent rinse waters.

In addition, a material balance was constructed from all the rinsewaters and daily dumps to the process drains and the feed to the wastewater treatment system over days 1-4. (This mass balance primarily represents the rinse waters as most of the dumps are done on day 5.)

Copper Inputs (kg)	
Rinses	
Sensitizing	
Alkaline cleaner rinse	0.014
Microetch rinse	4.404
Acid rinse	0.115
Electroless	0.259
Acid rinse	0.019
Electroplating Line	
Microetch	0.191
Floor capture	0.276
Electroplating	0.607
Etch rinse	0.600
Oxide Area	
Deburrer	0.653
Etch	0.025
Dumps	
Electroplating Line	
Microetch rinse	0.048
Electroplate rinse	0.235
Etch rinse	0.180
Total	8.346

▼

Drains

▼

Copper Outputs (kg)	
Treatment plant influent (total)	9.192

Steps 12 and 13: Evaluating and refining the material balances

The material balances for the sensitizing and electroplating lines were considered to be very satisfactory and reflected well on the sampling and analytical study. In order to derive a preliminary material balance for the oxide coating area and water treatment area, a number of assumptions and estimates (by difference) had to be made. This led to good agreements but the estimates had to be backed up by further monitoring and information gathering.

The material balance for the copper inputs to the drains and the drain output to the wastewater treatment plant also showed a good agreement considering the complexity of the printed circuit board manufacturing plant and the large number of waste copper sources. Approximately 91 percent of the copper loading into the treatment plant during production days 1-4 was accounted for by the measured wastewater sources. The extra 9 percent was probably due to copper being washed from contaminated floor areas and further minor sources of copper which were not included in the survey (e.g. gold plating line). A decision was made to refine the material balance in an ongoing waste monitoring program.

A number of important conclusions could be drawn from the material balance information:

- The microetch rinse accounted for approximately 90 percent of the total sensitizing area copper loading.
- The microetch rinse accounted for approximately 56 percent of the plant's total rinsewater copper loading on the treatment plant.
- Other major sources of rinsewater contamination were the electroplating rinse, sulphuric/peroxide etch rinse and the deburrer (oxide area) rinse.

Phase Five: Waste reduction alternatives

Step 14: Obvious waste reduction measures

From the information accumulated from the waste audit and observations which were made while investigating the plant in detail a number of obvious waste reduction and efficiency improving measures were identified. These are again split into the four processing areas and the wastewater treatment plant.

a) Deburring operations (sensitizing area)

From the studies on the deburring, or surface conditioning operation, it was noted that the sand filter was backwashed with return (dirty) water which would lead to entrainment of copper fines throughout the sand bed. This could lead to fines being released into the filtered water. The deburred spray water had a suspended solids concentration of 104 mg/L. This high concentration probably accounted for the fine powder layer which was observed on the printed circuit boards after the deburrer drier. This represented an input of copper into the sensitizing line (0.04 kg/week).

The waste copper fines which were collected on the backwash bag filter system were shipped to secure landfill with the sludge cake from the filter press. However, the fines are relatively pure copper and investigations confirmed them to have a value of approximately $1.0/kg.

b) The sensitizing line (electroless plating)

As discussed previously, the results of the wastewater characterization showed that a very high copper loading was from the microetch rinse. This copper source represented 90 percent of the sensitizing rinsewater copper load. The sensitizing line is a manually operated plating line and it was observed that no drip time was used after the microetch. A one minute drip time was subsequently implemented and a monitoring programme initiated to record improved waste loadings. A static rinse drag-out tank could also be used to reduce the running rinsewater loading from this source.

c) Electroplating line

It was noted that the recirculation pumps on the copper electroplating line had leaking mechanical seals leading to copper crystallization on the pump shafts and surrounding floor areas. This copper material was subsequently picked up by the developer rinse, which flowed directly onto the floor, and discharged to the floor drain leading to Pit 1. The copper loading from this source at one floor drain close to the electroplate rinse was approximately 70 g/day. A satisfactory maintenance programme to prevent these leaks and installation of drip trays and general cleanliness in the copper electroplating areas could reduce this source of waste loading on the treatment plant. Good housekeeping in all copper processing and handling areas could prevent copper waste loading from other areas (e.g. the copper etch and crystallization) from reaching the drain system.

d) Oxide coating area

The rinsewater from the deburrer in the oxide coating area was discharged directly to the process drain. A bag filter was attached to the pipe at the outlet to the drain but during the in-plant study the capturing device was inefficient, leading to significant quantities of copper fines being released to the drain system. Contact with acid wastewaters would subsequently dissolve the fines in the process drains. A closed loop filtration system similar to the one in the sensitizing area was added, eliminating this source of waste copper.

e) Wastewater treatment system

A number of inefficient operations in the wastewater treatment system were highlighted in the waste audit. First, alum was added to the pH-corrected (pH 8.5) wastewater in Pit 1. Alum is an effective coagulant for colloidal material but is not necessary for metal hydroxide precipitation and increases the volume of sludge produced.

Second, the existing sedimentation basin, a legacy from a former wastewater treatment system, was observed to be of inappropriate design, suffering from inadequate sludge removal capability, accumulation of sludge and floating sludge creating effluent discharge problems.

Third, in an effort to overcome the periodic high levels of copper being discharged to the sanitary sewer, two sand filters were installed in parallel after the sedimentation tank. However, from the results in Figure 6, it can be seen that the sand filters were not effective in removing suspended solids or copper from the wastewater.

Assuming a 50 percent reduction of copper loading from the sensitizing microetch rinse through improved rinsing, and elimination of the copper loading from the deburrers and electroplating area floor drain, a 40 percent reduction in rinsewater loading to the wastewater treatment plant could be achieved.

Step 15: Targeting problem wastes

From Figure 6 it can be seen that the sand filter input concentrations of suspended solids and copper are approximately equal to the output concentrations from the filter. Furthermore, the copper discharged to the sanitary sewer was primarily dissolved (75-95 percent of total copper concentration) and in excess of the municipal by-law limits on days 2 and 5. Previous experience with the treatability of the printed circuit board wastewaters had established that the electroless copper wastewaters were particularly difficult to treat because of the presence of chelating agents in the electroless copper plating solution. In addition, chelating agents were present in the resist stripping solution. It was noted that when the treated resist strip was dumped to Pit 2 on days 2 and 4, significantly higher copper concentrations were observed in the sanitary sewer discharge than on days 1 and 3. In the sensitizing and oxide areas, tanks were dumped on the Friday of each week. Consequently, Day 5 represents an atypical day for the wastewater treatment plant.

Wastewaters containing chelated copper and those containing a mixture of copper and chelated copper were therefore considered to be "problem wastes."

Treatability tests using alum, NaOH, lime and different flocculants were conducted on the pollutant sources individually and in combination. Table 1 shows the results of the treatability tests using lime for pH correction and 5 mg/L of an anionic flocculant. The tests indicated that most wastewaters containing copper could be treated very successfully by metal hydroxide precipitation. However, the chelating agents in the electroless rinse and resist strip rinse affected copper hydroxide precipitation and should therefore be segregated and treated separately.

The tests on the influent to the wastewater treatment plant indicated that copper could be reduced from relatively high concentrations to less than the by-law limit (5 mg/L) using lime and an anionic flocculant. In general, lime produced a more dense and settleable precipitate than caustic although it generated more sludge material.

Table 1: Treatability tests using lime and anionic polymer

Sample	*Raw/Treated*	*Total Copper in Supernatant (mg/L)*
Sensitizing		
Microetch rinse	Raw	260.0
	Treated	0.3
Electroless rinse	Raw	9.1
	Treated	9.0
Electroplating Line		
Microetch rinse	Raw	22.0
	Treated	0.2
Copper electroplate rinse	Raw	33.0
	Treated	0.2
Copper electroplate rinse	Raw	19.0
Resist strip rinse (50:50)	Treated	20.0
Electroplate floor drain	Raw	44.0
	Treated	0.1
Sulphuric/peroxide etch rinse	Raw	40.0
	Treated	0.1
Oxide Coating		
Microetch rinse	Raw	150.0
	Treated	1.1
Wastewater Treatment		
Influent	Raw	11 74 13 73 8.4*
	Treated	0.4 0.6 0.4 4.0 0.7

*Hourly grab samples

Step 16: Developing long-term waste reduction alternatives

While the waste reduction alternatives described in Step 14 will reduce pollutant loadings and result in significant cost savings, an efficiently designed and operated end-of-pipe treatment system was still considered to be the best means of ensuring that Company A's effluent discharge limits would be met consistently. The following section describes the wastewater treatment and recovery system design which was developed, with the assistance of a consultant engineering company, from the waste audit and treatability studies. The major points for consideration in the system design were:

- Segregation of all the chelate-containing wastewaters from the conventional metal hydroxide precipitation system.

- Segregation and separate treatment/recycling of all the chelate-containing rinsewaters and concentrated bath-dumps.

- Collection of all general bath dumps (non-chelate containing) in a holding tank for metering back to the conventional treatment system at a controlled rate (to prevent surges in copper loading).

- Upgrading of existing pH adjustment, polymer addition, clarification and sand filtration systems for efficient metal hydroxide precipitation and subsequent discharge of high quality effluent.

The sources of chelate containing wastewaters were as follows:

Source	*Flowrate (L/h) or Volume (L)*	*Copper Concentration (mg/L)*
Mild Alkaline Cleaner Bath	400L	63.7
Mild Alkaline Cleaner Rinse	518 L/h	0.8 (maximum 1.7 mg/L)
Electroless Plating Bath	588 L	11000
Electroless Plating Bleed	10 L/h	11000
Electroless Plating Rinse	770 L/h	7.7 (maximum 10.3 mg/L)
Resist Strip Bath	920 L	less than 5.0
Resist Strip Rinse	390 L/h	-

Information on the type of chelator or chelate concentration was not readily available from the chemical suppliers.

The resist strip rinse and mild alkaline cleaner rinse waters both had copper concentrations well below the by-law limits and could therefore be discharged directly to sewer. The resist strip rinsewater, however, would require coarse filtration (cartridge filter) to capture occasional carryover of gross resist suspended solids. The resist strip bath dump also had a very low copper concentration but required batch treatment to remove resist material before discharge.

The remaining wastes, the electroless plating bath, electroless bleed, electroless rinse and mild alkaline cleaner bath all contained copper in excess of the by-law limits and required treatment/recovery. Current waste treatment and recycling technologies were reviewed. Available treatment methods included sulphide and sodium borohydride precipitation. However, sulphide precipitation was not considered appropriate for the more concentrated solution and the sodium borohydride treatment, although effective, was costly and generated copper-containing sludge requiring subsequent disposal.

Recycling processes included electrolytic copper recovery and ion exchange. Ion exchange was not considered appropriate for the high concentrations in the spent plating baths and has not generally been applied to the recovery of chelated metals. However, electrolytic copper recovery, which is unaffected by the presence of chelates, has been used to recover copper efficiently from concentrated plating bath solutions down to 10 to 20 mg/L. The residual copper concentration would still be in excess of by-law limits and ion-exchange, using the new chelating type resins, could then be used to polish the wastewater prior to discharge directly to the sanitary sewer.

To reduce the volume of wastewater to be treated in the electrolytic recovery unit, a static drag-out rinse tank should be incorporated after the electroless plating tank and prior to the running rinse. The static drag-out tank would collect the majority of the copper drag-out load from the electroless plating tank and would then be dumped daily to the electrolytic unit for copper recovery. The subsequent running rinsewater would have a very low copper concentration and could be discharged directly to sewer (copper concentration now less than the by-law limit).

Efficient rinsing of plated products is a very important step in reducing rinsewater volumes and concentrations, and also in facilitating subsequent waste reuse and recovery. Figure 8 shows a general schematic diagram of a drag-out tank, counter-current rinsing, and associated waste recovery/recycling/treatment operations.

Figure 8: Drag-out tanks and countercurrent rinsing are used to reduce the total amount of water required to rinse the product and to concentrate the rinsewater for subsequent recovery.

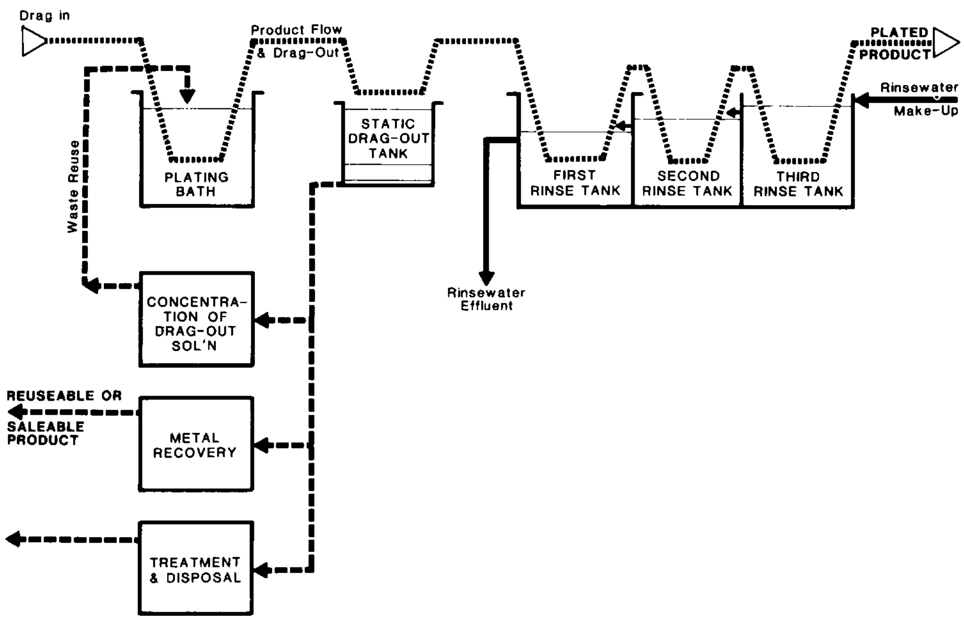


Figure 9 shows the schematic process flow diagram for the waste segregation and wastewater treatment system. The treatment system incorporates the following key elements:

- Collection of all non-complexed rinsewaters in a common sump for pH adjustment with caustic (or lime) to pH 9.0-9.5.

- Installation of static rinse tank after the electroless copper plating bath. The static rinse tank will collect most of the drag-out loading from the electroless plating bath and will then be dumped daily for electrolytic recovery. The subsequent running rinsewater (chelate-containing) will then be discharged directly to the sanitary sewer.

- Segregation, cartridge filtration and direct discharge of resist strip rinsewaters (chelate-containing) to clarified water basin.

- Segregation and direct discharge of electroless plating running rinsewaters and cleaner rinsewaters (chelate-containing) to clarified water basin.

- Segregation and collection of resist strip and developer dumps (or bleed) in a separate holding tank for pH adjustment and direct dis charge.

- Segregation and collection of electroless copper (chelate-containing) bath dumps, controlled bleed and drag-out tank contents together with alkaline cleaner (chelate-containing) and microetch (sensitizing) bath dumps in a separate batch recirculation tank for electrolytic copper recovery.

- Polishing of electrolytically treated solutions in a chelating ion ex change resin bed prior to discharge to clarified water basin.

- Segregation and collection of general bath dumps (e.g. microetches, pre-dips, acids, alkalis, etc.) in a holding tank for subsequent metering into the pH adjustment sump.

- Modification of the existing sedimentation tank to incorporate a clarified water holding basin and provision for capture of accidental spills and emergency waste storage.

- Although it is considered that the effluent copper concentration from the proposed treatment system will comply with the existing by-law limit of 5 mg/L, it was recommended that Company A's sand filters be up graded and included in the treatment scheme in anticipation of the proposed lowering of the by-law to 2 mg/L of copper. The clarified wastewater should be polished through a sand/anthracite dual media bed to increase the solids loading capacity of the filters.

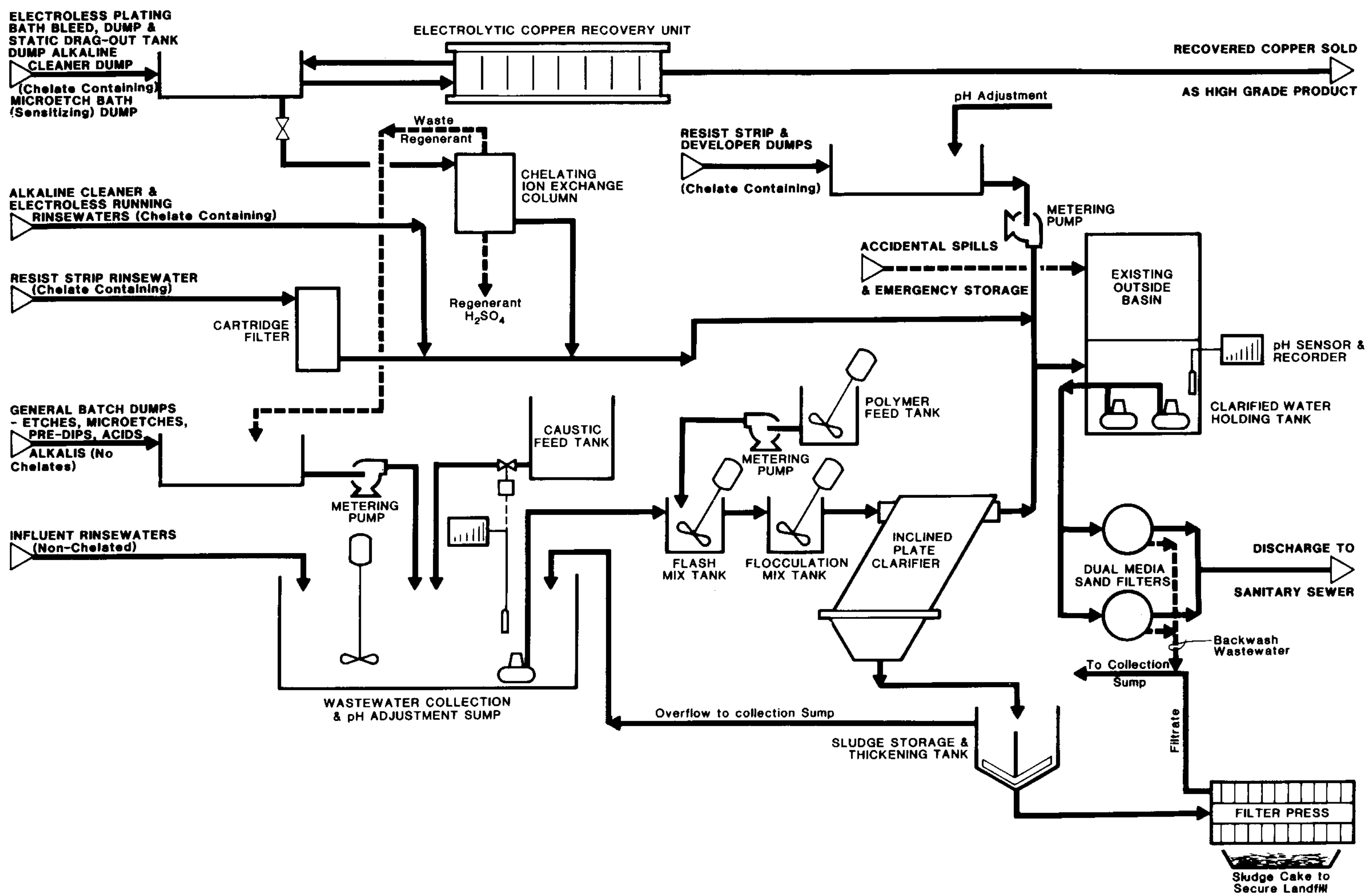


Figure 9: Process design for Company A's waste segregation and wastewater treatment system

- The sludge from the inclined plate clarifier should be pumped to a sludge storage/thickening tank. Thickened sludge will then be periodically pumped from the storage tank for dewatering in the filter press. The reduced volume of sludge cake will then be disposed of in a secure landfill site.

Phase Six: Cost/benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction

From the waste audit studies, the existing wastewater treatment system at Company A was found to be of poor fundamental design and a total upgrading of the treatment system was necessary. As Company A was facing legal action from the local municipality with respect to the violation of discharge standards, the return on investment was not of prime concern in this case study; of more importance was the development of the most cost-effective treatment/recycling system available.

From Step 16 a number of waste treatment recovery alternatives were identified and a process design subsequently derived on the basis of technical considerations. However, through the waste reduction opportunities described and the segregation and recovery of copper from the chelate-containing and microetch (sensitizing) wastes it was estimated that a cost saving of $25,000 per annum on sludge haulage and secure landfill disposal costs could be realized. In addition, it is estimated that approximately $4,000 per annum of copper could be recovered using the electrolytic recovery unit.

The total installed cost of the proposed system including the major equipment items (inclined-plate clarifier, sludge storage/thickening tank, filter press, electrolytic copper recovery unit, ion exchange unit) segregation pumping and piping, instrumentation and control and 40 m^2 building was $300,000. However, considering Company A's history of pollution problems, the impending legal action and the amount of time being spent by senior personnel on day to day waste management problems, the implementation of the waste segregation and treatment/recovery system could be considered money well spent and an investment for the future.

Step 18: Implementing your action plan: reducing wastes and increasing production efficiency

The results of the waste audit and the waste reduction/treatment studies were presented to Company A's management and plans were made to implement the recommended waste reduction measures and the treatment/recovery system.

The waste audit/reduction approach achieved the following objectives:

- Provided a sound understanding of all the sources of waste copper at the manufacturing plant.
- Identified and quantified the major sources of waste copper.
- Permitted evaluation of processing efficiencies from assembled information on unit processes, products, raw materials, water usage, and waste generation.
- Identified waste reduction opportunities.
- Eliminated some wastes and associated disposal problems.
- Identified "problem wastes" requiring special attention.
- Enabled the development of a cost-effective, integrated waste segregation and wastewater treatment/recovery system.
- Enabled the development of a waste management system which would comply with discharge regulations and result in improved public relations.

Case Study 2: Steel pickling

Autonut Limited, a manufacturer of nuts and bolts for the automobile industry, purchases 25,000 tonnes per year of rod steel from a local steel mill. The rod steel is machined into nuts and bolts in a series of processes. Steel develops a surface coating of oxidized iron, called scale or rust, which must be removed before machining begins. This rust and scale is traditionally removed by chemically reacting steel with sulphuric acid (H_2SO_4) or hydrochloric (HCl) acid, a process called pickling.

In the pickling process, steel is immersed in an acid bath which dissolves the scale and some of the iron. The steel is then removed from the bath and the acid is rinsed off. The steel then receives selected coatings and continues through the manufacturing process. Pickling causes an increase in the iron content of the acid which reduces pickling efficiency. Fresh acid must be added to the bath to maintain an efficient reaction rate.

Eventually, the iron content becomes too high for effective pickling and the spent pickle liquor must be replaced with fresh acid. Sludge which has settled to the bottom of the pickling tank must also be removed. Disposal of this spent pickle liquor, sludge and pickling rinsewaters creates a potential pollution problem.

Autonut had installed a high speed sulphuric acid batch pickling line in 1980. However, since the process was commissioned, environmental control regulations had tightened considerably. As a result, the company faced confrontations with regulatory authorities on air and water pollution as a result of acidic air emissions and discharges of high iron content and acidic rinsewaters which exceeded municipal by-law levels. As well Autonut paid about $380,000 annually for haulage and disposal of the spent pickle liquor.

Costs of fresh acid, water, electricity and labour were also increasing and the company wanted to increase its production capability.

What was the best and most cost effective solution to these problems? The company started off on the right track by conducting an in-plant study or waste audit of its pickling and waste treatment operations. As you will see, the company adopted a waste reduction strategy and increased its production efficiency while resolving pollution problems resulting from fumes and wastewater and it eliminated the expense of waste acid disposal.

Following is a description of the approach taken. Autonut management appointed a senior engineer to organize a team of employees to carry out the waste audit and subsequent waste reduction plan. The team consisted of the engineer, the pickling supervisor and a chemical technician. All other employees were made aware of the importance of the work through a newsletter and regular bulletins.

Step 1: Listing of unit processes

The engineer started off the study by walking around the pickling and waste treatment facilities, listing all the unit processes and making notes of their respective functions and use. He solicited opinions and assessments from all the plant supervisors who were familiar with the day to day operations. The unit operations are listed in Table 1. Extensive observations on how the units were operated were also recorded.

Table 1: Listing of Unit Processes

Unit Process	*Functional Description*
Pickle Tanks (2)	17.5 m^3, steel, rubber lined
High Pressure Spray Rinse Tank	30 spray rinse nozzles, supplied by 1000 L/min pump
Fume Scrubber	Packed bed wet scrubber with internal recycle
Storage Tank for 50% Caustic Soda	Bulk storage (20 m^3)
Neutralization Basin	Basin with rudimentary solids removal

In order to address the most pressing air and water pollution problems and the costly disposal of spent pickle liquor, the team agreed to focus the waste reduction audit on the following operations: pickling tanks, spray rinsing, fume scrubber and wastewater treatment. However, studies of other operations, (e.g. surface coating and steam generation) could also pinpoint additional areas of wastage and losses.

Step 2: Constructing a process flow diagram.

A flow diagram was then prepared to illustrate the interrelationship of all the unit processes (Figure 1). The engineer presented this process flow diagram to the team.

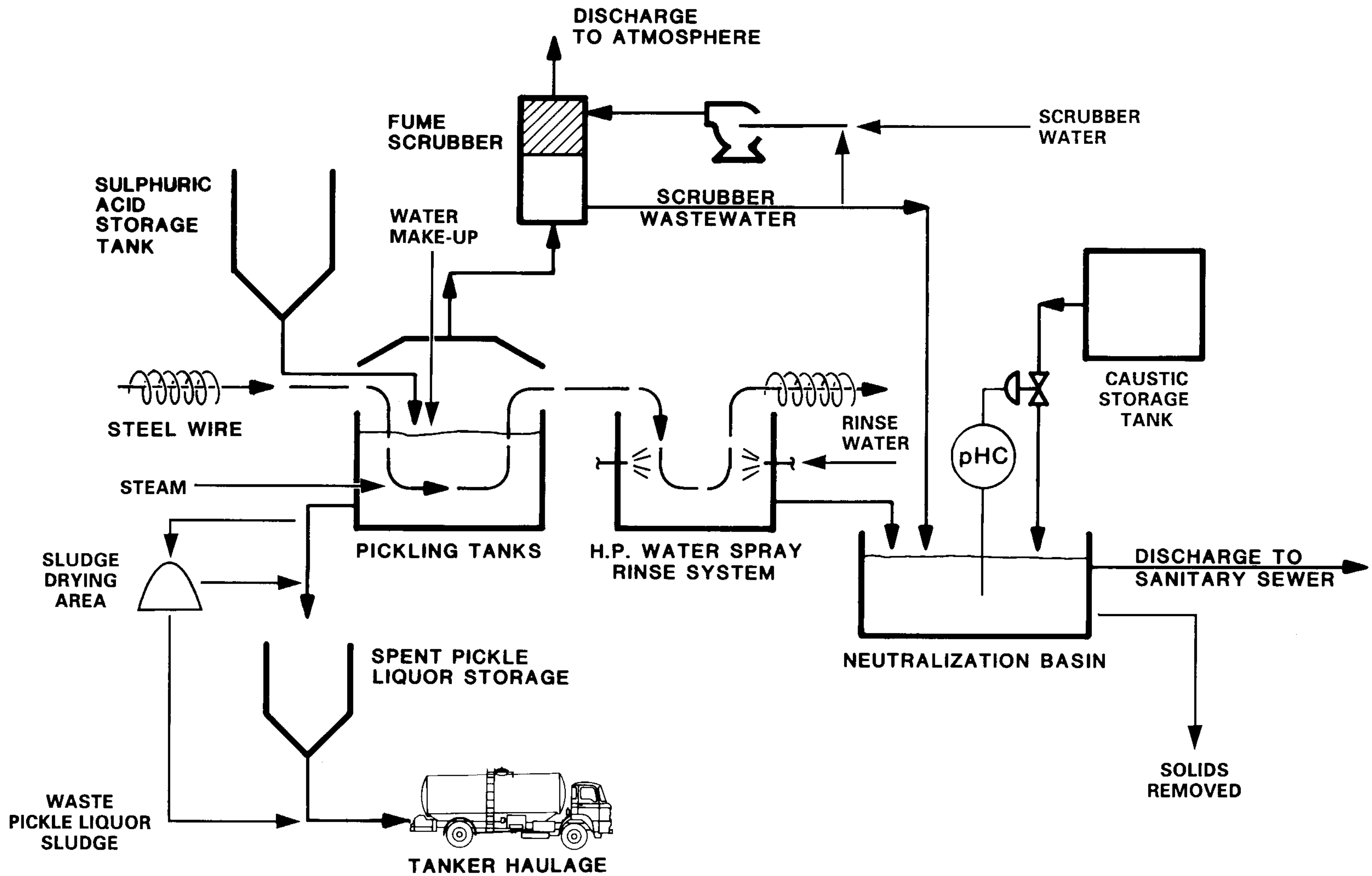


Figure 1: Schematic diagram of Autonut's pickling and wastewater treatment processes

Step 3: Determining resource usage

The waste reduction audit team assigned the engineer and chemical technician to determine the annual flow rates and the compositions of the inputs and outputs. They drew up a table listing the annual consumption of all the raw materials used (Table 2). The sulphuric acid was purchased at a concentration of 93%. The caustic was 50% sodium hydroxide. Since acid and caustic was also used by other areas in the plant, purchasing records could not be used to estimate annual consumption. Therefore, usage of acid and caustic in the pickling plant was measured during a typical production week and extrapolated for the full year.

To simplify matters the engineer estimated that the annual purchase of steel rod consisted of 24,750 tonnes iron (ignoring the fact that steel contains other elements as well) and 250 tonnes of FeO (to average out the iron and various iron oxide components in the rust and scale).

Table 2: Annual usage of raw materials

	Annual Raw Material Usage (all tonnes per year expressed as t/a)		
Unit Process	*Sulphuric Acid (93%)*	*Rod Steel*	*Caustic (50%)*
Pickling	660	25,000	
High Pressure Rinsing	-		
Fume Scrubber	-		
Neutralization Basin	-		106

Step 4: Raw material storage and handling losses.

Due to the nature of the two major raw materials, steel and sulphuric acid, it was considered that no significant handling losses were occurring. However, company records did seem to indicate that length of storage time for the steel might have an effect on the actual pickling times required, probably due to increased rust formation. As part of the audit the waste reduction team undertook to measure the weight loss during pickling of samples stored for different lengths of time.

Step 5: Recording water usage.

The next step was to account for the water consumption at the pickling plant. The total water consumption in the pickling plant was recorded at 29,700 m^3 per year (equivalent to tonnes per year). This water was used for the baths, make up, rinsing, steam production and clean-up.

Flow measurements of the spray rinsewaters indicated that most of the water consumption was for rinsing only. The engineer observed the spray rinse system in operation and made a note that this was a definite area for waste reduction.

The engineer observed the pickling tanks in operation on several occasions and noted that the live steam injection (direct injection of steam into the pickling tank) which was being used for heating and agitating the pickling bath did not seem to be giving uniform and thorough agitation to the acid solution. This could affect the efficiency of the pickling process.

The water was consumed as follows:

Table 3: Water Consumption

Use	*Quantity Used m^3/yr.*
Make up water in the pickling tank	1,702
Steam generation	1,600
Water used to rinse the steel	24,300
Scrubber water	900
Total water consumption	29,700

Step 6: Measuring current levels of waste reuse.

It was noted that no wastes were reused at the pickling plant.

Steps 3 to 6 were concerned with the inputs to the pickling plant and wastewater treatment. Steps 7 to 9 are now concerned with defining the outputs from these operations.

Phase Three: Defining Process Outputs

Step 7: Identifying process outputs.

The engineer and chemical technician also drew up a list of outputs which included product, intermediate flows within the pickling plant, airborne emissions, wastewater sewered and wastes which were hauled away for off-site disposal. All the process outputs were recorded in Table 4. The amount of descaled rod steel produced was easy to determine from production records. Steps 8 and 9 discuss how the wastewater and wastes were determined.

Table 4: Process outputs

Unit Process	*Product*	*Waste Reused*	*Airborne Waste*	*Wastewater Sewered*	*Liquid Waste*	*Solid Waste*
Pickling liquor	De-scaled rod steel (24,750 t/a)	-	Evaporation and acid fumes	- liquor	Spent pickle sludge	Pickle
High Pressure Rinsing	Cleaned rod steel	-	-	24,300 t/a	-	-
Fume Scrubber	High pH waste-water to treatment	-	Evaporation	900 t/a	-	-
Neutralization Basin	Dischargeable wastewater	-	-	27,000 t/a[1]	-	(small quantity)

[1] Includes the spray rinse wastewater.

Step 8: Accounting for wastewater flows.

All wastewaters discharged to the sanitary sewer from the pickling and rinsing operations were pH adjusted. The wastewater discharged to the sanitary sewer was analyzed and the flowrate was measured. Of the 27,000 m^3/annum discharged, 24,300 m^3/annum was from the rinsing operations.

Records of wastewater discharged to the sanitary sewer indicated that the pH of the effluent was subject to periods of overdosing and under-dosing of caustic. In addition, the public works authorities were concerned with the large amounts of iron hydroxide being discharged and were threatening to prosecute Autonut for violations of the sewer use by-law.

Step 9: Documenting wastes stored and hauled off-site for disposal.

According to waste disposal records, 2,191 t/a of spent pickle liquor was disposed of at a local oil recovery facility at cost of $361,000 per year. In addition when the pickle tanks were pumped out, considerable sludge (100 t/a) was found in the bottom of the tanks. This sludge (ferrous sulphate) was shovelled into containers and dumped in a sludge drying area, allowed to drain and then hauled off-site to disposal. The quantities of waste hauled off-site to disposal are recorded in Table 4.

Operators added acid as they observed that pickling rates were decreasing. The iron concentration was monitored and when it reached 7% iron by weight, acid was no longer added and the whole bath was dumped.

An old analysis of one spent pickle liquor bath determined that the free acid content was 4 percent H_2SO_4. One shipment of the pickle liquor sludge had also been analyzed. The iron content was determined to be 25 percent and the total sulphate was 31percent.

The engineer checked Autonut's Generator Registration records and confirmed the classification of the spent pickle liquor and sludge, as a hazardous waste, having a waste classification number 111 C. The "C" designation described its primary characteristic as corrosive. No other liquid or solid wastes were registerable under O. Reg. 347 of the Environmental Protection Act.

Phase Four: Material Balance Study

Step 10: Listing of process input and output information.

Using the basic mass balance principal of "what goes in, must come out" the engineer decided to list all the input and output information in order to determine the adequacy of the information already accumulated.

The team drew up a list of the inputs and outputs (Table 5) and decided what parameters were important for each input/output. In addition to the total quantities, the team realized it would be necessary to track the major chemical constituents, total sulphate and iron. Tracking the sulphate ion was important because it indicated the consumption of a primary raw material, namely sulphuric acid. Iron was also important because it was the major contaminant of the waste streams and its concentration in the wastewater was above the sewer-use by-law. The team used the compositions of each input/ouput, as determined in Steps 3 to 9, in order to obtain the sulphate and iron quantities in each stream.

The team considered iron loss from the steel rods to be an input to the process. Iron in the steel rods which passed through the pickling process, was not listed as either an input or an output since the large quantity would mask variations in other outputs of iron, such as wastewater and wastes sent for disposal.

To determine the annual iron loss from the unpickled steel, the engineer determined the average weight loss of a variety of samples during the pickling process. Iron loss is made up of scale removed and base metal dissolved, a mixture of iron (Fe) and iron oxides (FeO). The 250 tonnes of iron loss from the steel rod was listed as the input to the process.

The rinsewater was sampled and analyzed for sulphate and iron. From this result, the dragout of pickle liquor could be calculated. The rate of evaporation was determined by measuring the change in level of solution in the pickle tank and subtracting the dragout rate.

Table 5: Process Inputs and Outputs

Pickling process

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Iron loss	250		194
Sulphuric acid feed (93%)	660	601	
Water (make up in the pickling tank)	1,702		
Steam	1,600		
Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Dragout (from pickling)	275	60	19
Evaporation	1,125		
Spent pickle liquor	2,191	349	153
Pickle liquor sludge	100	34	25

Neutralization Basin

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Rinsewater	24,325	60	19
Scrubber wastewater	900		
Caustic soda	106		
Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Discharge to sewer	27,000	68	23
Solids			

Step 11: Deriving preliminary material balances.

Preliminary material balances were then constructed for the pickling process and neutralization basin as in Figures 2 and 3.

Figure 2: Preliminary material balances on the pickling process.

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Iron loss	250		194
Sulphuric acid feed	660	601	
Make up water in the pickling tank	1,702		
Steam	1,600		
Total	4,212	601	194

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Pickling Process

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Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Dragout (from pickling)	275	60	19
Evaporation	1,125		
Spent pickle liquor	2,191	349	153
Pickle liquor sludge	100	34	25
Total	3,691	421	197

Figure 3: Preliminary material balances on the neutralization basin

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Rinsewater	24,325	60	19
Scrubber wastewater	900	< 1	
Caustic Soda	106		
Total	25,331	60	19

Neutralization Basin

Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Discharge to sewer	27,000	68	23
Solids	< 1		< 1
Total	27,000	68	23

Step 12: Evaluation of material imbalances.

From the pickling information (Figure 2), a 177 t/a sulphate imbalance was identified. This represented 29% of the measured input of sulphate. The waste reduction audit team agreed that this discrepancy was too large and apparently indicated that either a waste stream was missing or some of the data was unreliable.

The engineer retraced the process to find any other sources of waste. As a result it was discovered that some cleaning operations generated additional wastewaters that went to the neutralization basin. However when these were analyzed, they were found to contain only negligible quantities of sulphate and iron.

The team decided that the source of the discrepancy was unreliable data and decided to repeat all the sampling and flow measuring over a three-week period. The three-week period was selected in order to audit at least three cycles of pickle liquor bath pump outs. As well the composition of each spent pickle liquor bath was analyzed. By monitoring three cycles the team felt that any variations would be averaged out and a better projection of annual rates would be obtained.

Step 13: Refining the material balance.

The three week sampling period revealed that the free acid content in the spent pickle liquor was much higher than previously thought. On average, the free acid level was 10 percent H_2SO_4. The other data remained the same.

With the new concentration of free acid, the sulphate balance on the pickling process improved and was now within 5 percent. The material balance difference on the total quantities remained at 14 percent. For the neutralization basin, the additional wastewaters were now also included and improved the water balance. The team decided that the new material balances were now acceptable. The refined material balances are shown in Figure 4 and Figure 5.

Figure 4: Refined material balances on the pickling process

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Iron loss	250		194
Sulphuric acid feed	660	601	
Make up water in the pickling tank	1,702		
Steam	1,600		
Total	4,212	601	194

Pickling Process

Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Dragout (from pickling)	275	60	19
Evaporation	1,125		
Spent pickle liquor	2,191	478	153
Pickle liquor sludge	100	34	25
Total	3,691	572	197

Figure 5: Refined material balances on the neutralization basin.

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Rinsewater	24,325	60	19
Scrubber wastewater	900	< 1	
Other water usage in the plant	1,225	< 1	< 1
Caustic soda	106		
Total	26,556	60	19

Neutralization Basin

Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Discharge to sanitary sewer	27,000	68	23
Solids removed from basin	< 1		< 1
Total	27,000	68	23

Step 14: Obvious waste reduction measures.

The new data was organized by the engineer and presented to the waste reduction audit team. Over the course of a couple of sessions, the team brainstormed to arrive at practical alternatives to reduce the following waste streams:

- spent pickle liquor
- pickle liquor sludge
- spray rinsewater
- pickling tank fumes

Spent pickle liquor and sludge are inevitable wastes from the existing pickling system. The team determined that the pickling process could be optimized to lower the concentration of free acid and that improved inventory control of steel rod would reduce rust formation. Both of these actions would contribute only a small reduction in the volume of spent pickle liquor. As a result they were given a low priority. However, the existing method of rinsing the rod steel using automatic high pressure sprays at about 1,000 litres per tonne of steel was an obvious and large source of waste.

It was noted that a high level of pickling bath "drag-out" was occurring and that the high pressure sprays were particularly inefficient. As a result, significant quantity of acid was being lost from the system and large quantities of acidic wastewater required pH adjustment before discharge to the sewer. This was another obvious area for waste reduction.

During the brainstorming sessions, the team agreed that best method to reduce the rinsewater wastage was through counter-current rinsing of the steel. In addition, it was agreed that steam agitation should be replaced with air agitation. Heating would be accomplished by installing an external heat exchanger. The engineer and the pickling plant supervisor were assigned to work out the details of these plans.

The engineer found that one of the least expensive techniques for counter-current rinsing after batch pickling was to use the dip and spray system. After dipping in the rinse tank, the work is held over the tank and a spray of fresh water is then activated and applied to the work to remove the slightly contaminated rinsewater remaining on the steel. This slightly contaminated rinsewater is then collected in the rinse tank.

This method would reduce the rinsewater requirement from an inefficient 1,000 litres per tonne of steel to less than 100 litres per tonne. In this manner, very significant savings in rinsewater consumption would be achieved.

Furthermore, by changing the method of agitation and heating, the pickling bath would have a negative water balance; that is, water would be lost from the pickling tank by evaporation instead of being introduced by the condensation of steam. As a result, the sulphuric acid would not be diluted. In addition, the dilute acid solution from a counter-current rinsing system could be balanced with the evaporation rate and used as make-up volumes in the pickling tank, thereby reusing acid and completely eliminating the rinsewater discharge.

The air agitation system would also increase pickling efficiency by improving mixing, and would increase evaporation from the pickling tank. The pickling plant supervisor discussed these measures with the operators and it was confirmed that these changes were feasible and practical.

With respect to the acid fume problems, the team evaluated fume exhaust systems. It was determined that an acid fibre filter which collects the acid mist and returns it to the pickle tank while releasing water vapour to the atmosphere would be a major improvement over the existing wet scrubber system which produced large volumes of contaminated wastewater.

The team had used information obtained in the waste reduction audit to determine modifications which would eliminate two sources of contaminated water, reduce acid fume emissions and recover sulphuric acid for reuse in pickling tanks. Having found efficient ways to address the rinsewater and acid fume waste problems, the waste reduction audit team moved on to Step 15.

Step 15: Targeting problem wastes

Step 14 listed the major wastes identified from the waste audit. The "problem" waste streams are the spent pickle liquor and pickle liquor sludge. Due to its corrosive nature, the spent pickle liquor was classified as a hazardous waste under Regulation 347 and therefore its disposal options were limited. The waste pickle liquor sludge is ferrous sulphate monohydrate—a potentially useful chemical with coagulant properties and with potential value for phosphorous removal applications at wastewater treatment plants.

As a result of the audit, a much better understanding of the waste composition was obtained. The team learned that acid loss due to disposal was much higher than first thought. Acid recovery had been discussed in the past by the company, but the characterizations of the waste streams and the material balance calculations of the audit gave the team the reliable data required to justify the purchase of an acid recovery unit as an economically attractive investment.

The characterization results and available options are shown in Table 6.

Table 6: Waste Characterization

Waste	*Analysis*	*Annual Quantity*	*Present Method of Disposal*	*Available Waste Reduction/Treatment Technologies*
Pickle liquor	10% H_2SO_4 7% Fe	2,191 t/a	Off-site	1. Acid Recovery 2. Neutralization
Pickle liquor sludge	40% $FeSO_4 \cdot H_2O$ 10% FeO (50% solids by weight)	100 t/a	Off-site	1. Off-site Reuse

Step 16: Developing long-term waste reduction alternatives

The team decided that three long term waste reduction/treatment options were available to the company. These were:

Acid Recovery (Option A)
In the acid recovery process, the spent pickle liquor would be pumped to a crystallizer where the iron salts would be crystallized from the spent pickle liquor by cooling. The remaining acid solution would be separated and brought up to pickling strength with the addition of fresh acid. The net effect of the acid recovery system would be to recover the sulphuric acid for reuse, instead of discharging it as waste. In addition, ferrous sulphate crystals would be generated and could be sold as a by-product.

The acid recovery system could be effectively combined with the waste reduction measures described in Step 14, such as a) balancing water into and water out of the pickling tank through the installation of indirect heating, air agitation and counter-current rinsing systems and b) installing an improved fume exhaust system with acid recovery. The combination would avoid any need for treatment or off-site disposal.

Neutralization (Option B)
In this option, a large neutralization system would be installed. The spent pickle liquor and rinsewaters would be combined and neutralized with lime. This process would produce a calcium sulphate/iron hydroxide sludge which would require subsequent dewatering and disposal.

Current Method
This option entailed renewing contracts with haulage companies which find the most economical means for disposing of the hazardous spent pickle liquor. In Autonut's case, the haulage company had been transporting the spent pickle liquor to an oil recovery facility. Autonut had to pay for haulage and disposal fees.

Although no major investment costs would be incurred with this option, the Autonut management was hoping to become less dependent on off-site disposal due to the high disposal costs. However, if Autonut selected this option it would still have to upgrade its existing wastewater treatment facility and deal with its air emissions.

Before any of the above three options could be implemented the waste reduction team would need to justify the action plan to management. The waste audit team decide to develop cost/benefit analyses for the three options.

Phase Six: Cost/Benefit Analysis and Implementing the Action Plan

Step 17: Cost/benefit analysis of waste treatment/waste reduction

The team proceeded to compare the economics of the acid recovery system, the neutralization system and the existing contract hauling option. From discussions with suppliers of acid recovery systems, the engineer determined the capital and operating costs of an acid recovery system. In addition, capital and operating costs for a neutralization system were obtained from appropriate suppliers. The results of the cost/benefit analyses are shown in Table 7.

Table 7: Comparison of economics for treatment/reduction options at Autonut Ltd.

(All costs in thousands of dollars)

Item	*Basis*	*Current Method*	*Acid Recovery Option A*	*Neutralization Option B*
Capital Investment	25,000 t/a pickling plant	0	800	1,200
Labour				
Operators	$25,000/man-year	12.5	25.0	25.0
Foreman	$30,000/man-year	0	3.0	7.5
Utilities				
Steam	$11/1000 kg	17.6	17.6	17.6
Water	$0.35/m^3	10.5	1.2	10.5
Electricity	$0.04/kWh	2.5	10.5	6.5
Raw Materials				
H_2SO_4 (93%)	$110/tonne	67.5	36.0	67.5
Waste Disposal				
Pickle Liquor	$165/tonne	361.0	0	0
Pickle Liquor Sludge	$177/tonne	17.7	0	0
Neutralization Sludge	$40/tonne	0	0	59.0
Wastewater Costs				
Caustic	$450/tonne	23.9	0	0
Lime	$75/tonne	0	0	36.1
Sewer Fees	$0.35/m^3	9.4	0	9.4
Maintenance	6% investment	0	48.0	72.0
By-Product Credit[2]	$FeSO_4 \cdot 7H_2O$ crystals	0	(9.1)	0
Total Annual Cost		521.9	132.2	311.1

Total Annual Cost Saving for Acid Recovery System	=	\$521,900 - \$132,200	=	\$389,700
Payback Time[1]	=	$\frac{\text{CAPITAL COST}}{\text{SAVINGS}}$		
	=	$\frac{\$800,000}{\$389,700}$	=	2.0 years
Total Annual Cost Saving for Neutralization System=		\$521,900 - \$311,100	=	\$210,800
Payback Time[1]	=	$\frac{\$1,200,000}{\$210,800}$	=	5.7 years

Note 1: The engineer's calculations did not consider interest on investment, as he initially wanted to determine a straight-line payback period. Of course interest on investment must be taken into account when detailed return on investment calculations are made. Other items like depreciation allowance, additional costs for upgrading the current wastewater treatment system (if contract hauling is maintained) and the escalating costs of waste disposal must be factored in.

Note 2: Autonut was responsible for hauling the ferrous sulphate crystals ($FeSO_4 \cdot 7H_2O$) to a chemical company (\$17/tonne) and received payment for the crystals in return (\$27/tonne).

These calculations show a savings of \$389,700 per year in operating costs which means that the acid recovery unit would pay for itself in about two years if interest on investment is not taken into account.

Step 18: Implement the action plan: reducing wastes and improving production efficiency.

The engineer presented these cost/benefit analyses to the waste reduction audit team. The team formulated recommendations to purchase and install an acid recovery system, balancing water into and out of the pickling tank, installation of indirect heating, air agitation, counter-current rinsing systems, and installing an improved fume scrubber with acid recovery (as described in Step 14). Chemical companies were also contacted and lined up to market the ferrous sulphate by-product.

The waste reduction team prepared a report which outlined the recommendations, an action plan, the costs involved, the benefits, both economic and environmental, and a schedule for implementation.

The results of the waste audit, the cost/benefit analyses and the recommended action plan were presented to a specially convened meeting of Autonut management. Management was quickly convinced that they had been wasting valuable resources for years, and they agreed that by installing the acid recovery system they would save on raw materials as well as eliminate waste and pollution problems. Furthermore, the pickling efficiency was expected to be improved by some 25 percent through better control of the pickling bath acid concentration and the improved agitation which would accommodate the company's plan to increase production.

Motivated by environmental and economic pressures, Autonut personnel came to realize that production efficiency, waste management and pollution concerns were interrelated. Through hard work and a deliberate waste audit/waste reduction approach, and by implementing their action plan, they succeeded in:

- improving process efficiency
- saving on raw materials
- eliminating waste and disposal problems
- improving relations with regulatory authorities and local residents.

Because of the benefits gained through conducting a waste audit on the pickling process, the company proceeded to conduct a similar study in the manufacturing plant.

Case study 3: Detergent manufacturing

Sud Chemical is a detergent manufacturing facility in a popular resort area of Ontario. It produces a large number of intermediate and final detergent based products which are generally manufactured by batch processing in response to customer demand. The plant's processes, therefore, involve frequent changeovers from one product to another which result in significant quantities of wastewater being generated from process equipment cleaning operations.

Overall, the plant produces a relatively high volume, concentrated and complex wastewater which used to be discharged directly to a small lake popular for recreational activities. However, in response to complaints from cottage owners and pressure from the Ministry of Environment and Energy (MOEE), Sud Chemical installed a concrete aeration basin to pretreat the wastewater before discharge to the lake. Unfortunately, the aeration basin did not perform up to expectations and very low organic removals were achieved, particularly in the winter months. Consequently the MOEE issued a final control order on Sud Chemical, giving it a limited period of time to clean up the wastewater or face plant closure.

Sud Chemical was unsure how to approach its problem. Various alternatives had been proposed by different companies to improve the wastewater treatment system but Sud Chemical was not convinced these systems were adequate and the projected costs were considered to be far too high. Having established that the "end-of-pipe" wastewater treatment option was prohibitively expensive, Sud Chemical management decided to move back up the pipe and see if waste reduction at source could be implemented. The plant chemist contacted OWMC for advice.

Since the plant chemist was the person most familiar with all the chemical processing operations and the water usage at the plant, he was designated as the waste audit supervisor. The following case study describes the waste audit/waste reduction approach taken.

Phase One: Defining process inputs

Step 1: Listing of unit processes

The plant chemist started off his waste audit by identifying the major unit processes at his plant and then proceeded to accumulate as much information as he could about them. He found that he was collecting so much information that he opened a file for each process. The processes were listed as in Table 1.

Table 1: Major Plant Processes and Brief Functional Description

Unit Process	*Brief Functional Description*	*File No.*
Alkylphenol synthesis	Alkylation of phenol for external sales and as intermediate for production of wetting agents	1
Non-ionic detergent synthesis	Ethoxylation of alkylphenol to make industrial wetting agents	2
Amide synthesis	Reaction of fatty acids and fatty amines with ethanolamines to make amide type foam stabilizers	3
Sulphonated anionic detergent synthesis	Sulphonation of alkylated benzenes to make linear alkyl benzene sulphonates (LAS)	4
Cationic detergent synthesis	Reaction of tertiary amines with methyl chloride to produce a quaternary ammonium chloride (for fabric softening)	5
Detergent formulation	Blending of tertiary chemicals to produce final detergent products	6

Step 2: Constructing a process flow diagram

A schematic flow diagram was then prepared to show the inter-relationship of the process (Figure 1).

Once all the unit processes were identified and described, the plant chemist proceeded to assemble information on raw materials, handling losses, water usage and waste reuse as shown in the following Steps 3 to 6.

Because of the complexity of Sud Chemical's processes and the large number of unit processes involved, only the alkylphenol production process will be described in detail in the waste audit section (Phases 1 to 4) of this case study. The waste reduction strategy is then discussed for the whole plant in Phases 4 and 5.

Phase Two: Defining process inputs

Step 3: Determining annual raw material usage

The plant chemist then began sifting through the company's accounting and purchasing records to determine the precise quantities of utilities, chemicals and supplies purchased. This aspect of the work also became a good check on measurements taken in the plant. The following information (Table 2) on raw material usage was obtained for the alkylphenol production process.

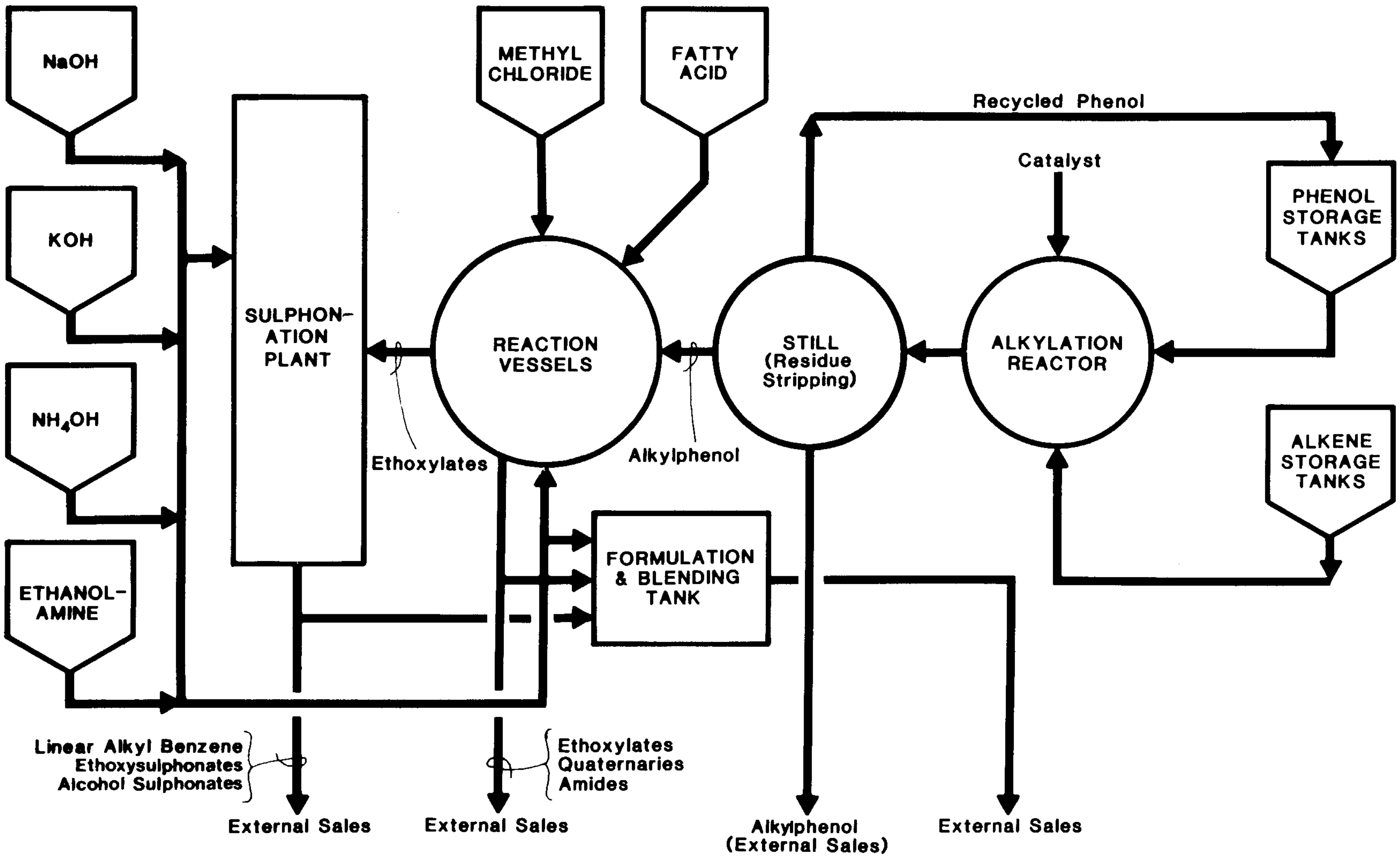


Figure 1: Schematic flow diagram of Sud Chemical's process

Table 2: Raw Material Usage

	Annual Raw Material Usage (tonnes)		
Unit Process	*Alkenes*	*Phenol*	*Catalyst*
Alkene storage tank	1400	–	–
Phenol storage tank	–	1000	–
Alkylation reaction vessel	1400	1000	2.4
Distillation	–	–	–

He was unable to obtain information on water usage from the purchasing records as all the water used for the cleaning and cooling processes was obtained directly from the lake. He determined the water usage through field measurements described in Step 5.

Step 4: Investigating raw material storage and handling losses

Due to the large number of raw materials used at Sud Chemical the plant chemist spent a long time accounting for the raw material storage and handling practices at the plant. His thoroughness was rewarded, though, and he was able to identify a number of losses which occurred through the plant. He noted down his observations and the reasons why losses were occurring.

In the alkylphenol production process, for example, he found that a significant quantity of phenol was lost as a vapour from the phenol storage tank vent and immediately recommended that a condenser system be installed.

Step 5: Recording water usage

The next step was to account for the water usage at the plant and determine what happened to the water. The plant chemist had no idea of how much water was being used in alkylphenol production and therefore decided to quantify its use. The washing frequency was directly related to changeover from one product to another. The plant chemist accurately recorded the product type and water usage over a two month period.

He determined that the still was washed out approximately once every week and that 7000 litres of water were used per clean out. He extrapolated this result to determine the annual water usage. The alkylation reaction vessel was washed infrequently and after speaking to his foreman he found out that it was cleaned out every six months with 8000 litres of water. He confirmed this by measurements in the plant.

The water consumption for the alkylphenol production process is shown in Table 3.

Table 3: Water usage in alkylphenol production

Water Use	*Quantity Used Per Annum (m^3)*	*Quantity of Wastewater Discharged to Treatment Per Annum (m^3)*
Alkylation Reaction Vessel Cleaning	16	16
Still Cleaning	350	350
Alkylation Reaction Cooling	2700	–
Still Condenser Cooling	2300	–

All the water used at the plant was obtained directly from the lake. Although no accurate consumption figures were available, the plant chemist estimated that a total of 1700 m^3 of water were used at the plant each day. He based his estimate on pumping records, pump data and a pumping test. Most of the water was returned directly to the lake although 250 m^3 per day of contaminated water was passed for treatment in the aeration basin.

While accounting for water usages the plant chemist realized that the vast majority of the wastewater was generated from the washing and cleaning processes and he made a note that this was an area for waste reduction.

Step 6: Measuring current levels of waste reuse

Some wastes were reused at the plant. In the alkylphenol production process unreacted phenol was stripped from the residue, in a distillation stage, for reuse back to the phenol storage tank. The plant chemist took measurements and estimated that 500 tonnes of phenol per annum were reused.

Phase Three: Defining process outputs

Step 7: Listing process outputs

The plant chemist listed the process outputs from the alkylphenol production process as below (Table 4).

Table 4: Process outputs

Unit Process	*Product*	*Waste Reused*	*Airborne Waste*	*Liquid Waste*	*Solid Waste*
Phenol Storage Tank	–	–	Vapour loss through vent	–	–
Alkylation Reaction	Alkylphenol/ plant & excess phenol (2900 tonnes)	–	–	washwater	spent catalyst
Distillation	Alkylphenol (2400 tonnes)	Phenol (500 tonnes)	–	washwater still bottom	–

He then proceeded to quantify these outputs in Steps 8 to 10.

Step 8: Accounting for wastewater flows

The plant chemist had determined the annual water usage in the alkylphenol production process in Step 5 and was therefore able to complete Table 5 as follows:

Table 5: Wastewater flows

	Discharge to		
	Treatment Plant		*Lake*
Source	*Flow (m^3/annum)*	*Concentration BOD (mg/L)*	*Flow m^3/annum*
Reaction Vessel Cleaning	366	2100	–
Cooling	–	–	5000

All plant wastewaters from the process equipment washing operations were collected in a common subsurface drainage system and passed to the aeration basin before discharge to the lake. The plant chemist sketched out the drainage system and identified the major wastewater points of entry. He was concerned that no capacity existed to divert or hold any spills or leaks and noted this in his records. The plant chemist estimated the wastewater flow to the aeration basin to be 74,000 m^3 per annum. He estimated that 450,000 m^3 of cooling water and uncontaminated process wastes were returned directly to the lake each year.

Step 9: Documenting wastes stored and hauled off-site for disposal

According to the company's waste disposal records, 3000 kg of spent catalyst and 8000 kg of still bottoms were hauled off-site each year. The spent catalyst and still bottoms are both regarded as hazardous wastes under Regulation 347 of the Environmental Protection Act.

Step 10: Listing of process input and output information

The plant chemist then began listing all the input and output information (Table 6) in order to conduct a material balance and to determine if there were any obvious information gaps.

Table 6: Process inputs and outputs

Alkylphenol Production Process

Inputs	Annual Quantity (tonnes)
Alkenes	1400
Phenol	1000
Reused Phenol	500
Catalyst	2.4
Cooling Water	9000
Wash Water	366
Outputs	**Annual Quantity (tonnes)**
Alkylphenol	2350
Reused Phenol	500
Still Bottoms	500
Spent Catalyst	3
Cooling Wastewater	9000
Wash Wastewater	366

Step 11: Deriving a preliminary material balance

A preliminary material balance was then constructed for the alkylphenol production process as in Figure 2. Cooling water and wash water were not considered in the mass balance as these inputs were assumed to equal the wastewater outputs. However, the quantities of organic material which were discharged in the wastewaters were subsequently estimated from measurements of chemical oxygen demand.

Figure 2: Preliminary material balance

Inputs (tonnes)	
Alkenes	1400
Phenol	1000
Reused Phenol	500
Catalyst	2.4
Total	2902.4

▼

Alkylphenol Production

▼

Outputs (tonnes)	
Alkylphenol	2350
Reused Phenol	500
Still Bottoms	8
Spent Catalyst	3
Total	2861

Step 12: Evaluation of the material imbalance

The plant chemist was confident that he had an adequate material balance for the alkylphenol production process. Furthermore, he estimated from the wastewater analyses that approximately 70 kg per annum of alkyl phenol was lost in the wastewater.

Step 13: Refining the material balance

The plant chemist developed the waste audit and material balances for all his unit processes. When he had finished he felt much more knowledgeable about his plant, its inputs, outputs, wastes and problems. By making critical observations and taking notes while he was conducting the waste audit he had also identified a number of waste reduction opportunities.

Phase Five: Waste reduction alternatives

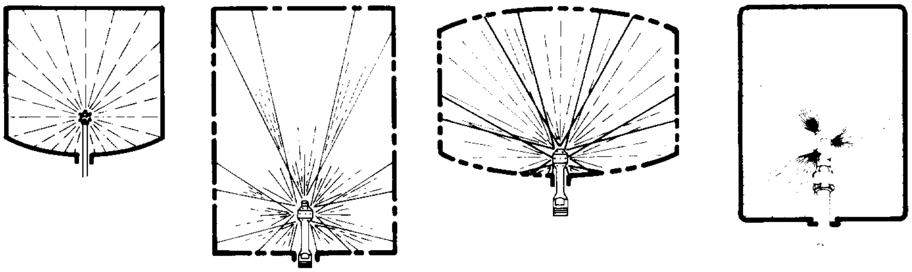
Step 14: Obvious waste reduction measures

During his audit, the plant chemist had measured wastewater flows and had also taken numerous samples for analyses. This information not only helped to refine his material balance but also helped to identify the major sources of pollution. The information he collected indicated that process equipment washwaters were by far the biggest source of wastewater and product loss in all the processing areas. Furthermore, he considered that the washout procedures, which he had taken for granted for years, were extremely wasteful.

The washout procedures involved filling the reaction vessels with water, cleaning with detergent, and then rinsing. The plant chemist decided to conduct some washout tests at the plant laboratory. He performed these tests with the object of producing a low volume concentrated washwater for potential reuse and for minimizing the total washwater volume. He found that by diverting the initial high concentration washwater to a holding tank he could prevent the bulk of the contaminants from entering the wastewater. Furthermore, product formulation tests indicated that product quality was not impaired when high concentration wastewater was blended back into production.

This was just the start of a concerted effort to reduce the volume and concentration of the wastewater requiring treatment. The following procedures were also implemented:

- Ball washers were installed to increase the efficiency of vessel washouts. Ball washers are spraying devices which give a powerful and thorough wetting of tank and vessel walls to provide effective cleanouts. A variety of ball washer systems are available for different sizes and shapes of vessels (see below).



- Improved product scheduling was initiated to minimize changeovers and corresponding required cleanouts. For example, the product formulation tank cleanout frequency was reduced from five to two times per week through better scheduling. Larger storage tanks were also installed to increase the length of production campaigns, further decreasing the number of cleanouts required. The plant chemist also started to dedicate tanks to specific products.

- Special washwater tanks were set up to hold wastewaters for subsequent use in detergent formulation.

- Tanks were either bought or modified to facilitate easy and efficient washout and drainage, (i.e. tanks were made to pitch, had rounded bottoms, were elevated from the floor and sloped to the exit valve).

- Simple leaks and dripping valves were repaired, packing glands on pumps were replaced by mechanical seals wherever possible and a new maintenance programme was initiated to keep equipment in good repair.

- Level controls and, in some cases, larger tanks were installed to prevent overflows.

- Monitoring of specific wastewaters was stepped up with the installation of good quality flow measuring equipment and increased sampling and analysis.

- Modifications were made to the wastewater drainage system to enable spills and leaks to be diverted and stored if necessary. In this way shock loadings of contaminants were prevented from disrupting the treatment system and causing environmental pollution.

- Probably as important as the practical waste reduction measures was the change in attitude of all employees towards the generation of waste, prevention of spills and water use. An education program was organized by the plant chemist which helped to make all employees more waste prevention conscious.

Everyone attended a series of talks entitled "Washing profits down the drain" which used photographic slides to show wasteful and poor processing techniques and improved practices resulting in waste prevention. An employee suggestion program gave financial bonuses for ideas which resulted in improved efficiency and waste reduction.

As a result of these efforts, the wastewater volume from the treatment facility was reduced by 40 percent (from 250 m^3/day to 150 m^3/day) and the total contaminant loading of the plant's wastewater (as measured by the chemical oxygen demand) was reduced by 50 percent.

Step 15: Targeting problem waste streams

The management at Sud Chemical was very pleased with the results of the waste reduction program. However, the MOEE, although equally impressed with the improvements made, were still unhappy about the contaminant loadings being discharged into the lake. The MOEE maintained that its control order stipulation for discharge of 15 mg/L biochemical oxygen demand, 15 mg/L suspended solids and 0.5 mg/L total phosphorus must be met. Having reduced their waste output considerably, the Sud Chemical management targeted their efforts to treating the reduced total plant wastewater stream.

The plant chemist decided to characterize his total plant wastewater and conducted an extended sampling programme. The average results are shown in Table 7.

Table 7: Characteristics of total plant wastewater

Parameter	*Average Wastewater Concentration (mg/L)*
Flow (m^3/d)	150 (m^3/d)
BOD	2400
pH	9 (pH units)
Suspended Solids	150
Total Phosphorus	3
Phenol	50

The high BOD (biochemical oxygen demand) indicated that a biological treatment process was required. But the presence of poorly biodegradable materials was of concern. The plant chemist proceeded to investigate wastewater treatment options in Step 16.

Step 16: Developing long-term waste reduction alternatives

The plant chemist decided to recommend that Sud Chemical employ a consulting engineering company in order to determine the best alternatives for the wastewater treatment system. He was satisfied that he had implemented good sound measures based on his waste audit to significantly reduce waste, but now realized that the upgrading of the wastewater treatment facility required specific expertise and engineering skills. The management of Sud Chemical agreed with the plant chemist's recommendation and an engineering company was retained to upgrade the treatment facility.

The upgraded system involved converting the existing aeration basin to an activated sludge treatment system with a secondary clarifier and associated sludge return pumping and pipework. Design points of particular interest included a floating cover and steam injection for temperature control during winter operation, addition of readily degradable substrate (methanol) to assist overall biodegradation (obtained by storing plant wastewaters) and addition of alum to assist secondary clarification and phosphorus removal.

Phase Six: Cost benefit analysis

Step 17: Waste treatment cost benefit analysis

Sud Chemical was placed in a position of having to upgrade its wastewater treatment system in order to comply with a control order from the MOEE. However, the cost of the upgrade system, based on the existing wastewater flow, was prohibitively expensive (approximately $1 million). In Sud Chemical's case, significantly reducing waste was the only practical waste management approach to take. By moving back up the pipe and conducting a waste audit on its processes, Sud Chemical was able to identify, segregate, and, in some cases, reuse its waste washwaters to achieve significant waste reduction.

The total cost of implementing the waste reduction measures described in Step 14 was approximately $50,000. Sud Chemical estimated that the savings made in reducing raw material use amounted to $20,000 per annum. This represents a straight line payback of investment of 2.5 years. More important, however, the waste reduction program significantly reduced the wastewater flow rate so that the existing aeration basin could be modified to an activated sludge system and the associated clarifier and equipment could be sized at approximately half the level required at the old flowrate. In this respect the total cost for the wastewater treatment plant upgrading of $500,000 represented a very significant saving compared to earlier cost estimates.

The waste audit approach, and subsequent waste reduction, almost certainly saved Sud Chemical from closing down. The plant is now thriving and production has increased by 25 percent. Not only has Sud Chemical managed to reduce water usage, raw material usage and waste loads but it also improved public relations and profits as well.

Chapter 4: Resources and information

Notice:
All information in the following chapter was correct at the time of publication.

Ontario Ministry of Environment and Energy Offices

Regional Offices

Hamilton: 119 King Street West, 12th Floor, P.O. Box 2112, Hamilton L8N 3Z9 (905) 521-7640
Kingston: P.O. Box 820, 133 Dalton Avenue, Kingston K7L 4X6 (613) 549-4000
London: 985 Adelaide Street South, London N6E 1V3 (519) 661-2200
Sudbury: 199 Larch Street, 11th Floor, Sudbury P3E 5P9 (705) 675-4501
Thunder Bay: P.O. Box 5000, 435 St. James Street South, 3rd Floor, Thunder Bay P7C 5G6 (807) 475-1205
Toronto: 7 Overlea Blvd., 4th Floor, Toronto, Ontario M4H 1A8 (416) 424-3000

District Offices

Barrie: 12 Fairview Road, Barrie L4N 4P3 (705) 726-1730
Belleville: Belleville Plaza, 470 Dundas Street East, Belleville K8N 1G1 (613) 962-9208
Cambridge: 320 Pinebush Road, P.O. Box 219, Cambridge N1R 5T8 (519) 622-8121
Clinton: c/o Ministry Agriculture & Food, 100 Don Street, P.O. Box 688, Clinton N0M 1L0 (519) 482-3428
Cornwall: 205 Amelia Street, Cornwall K6H 3P3 (613) 933-7402
Halton-Peel: 1235 Trafalgar Road, Suite 401, Oakville L6H 3P1 (905) 844-5747
Kenora: P.O. Box 5150, 808 Robertson Street, Kenora P9N 1X9 (807) 468-2718
Muskoka-Haliburton: 483 Bethune Drive North, Gravenhurst P1P 1B8 (705) 687-6647
North Bay: 1500 Fisher Street, Northgate Plaza, North Bay P1B 2H3 (705) 476-1001
Ottawa: 2435 Holly Lane, Ottawa K1V 7P2 (613) 521-3450
Owen Sound: 1180-20th Street East, Owen Sound N4K 6H6 (519) 371-2901
Parry Sound: 74 Church Street, Parry Sound P2A 1Z1 (705) 746-2139
Pembroke: 1000 Mackay Street, Pembroke K8B 1A3 (613) 732-3643
Peterborough: 139 George Street North, Peterborough K9J 3G6 (705) 743-2972
Sarnia: 265 N. Front Street, Suite 109, Sarnia N7T 7X1 (519) 366-4030
Sault Ste. Marie: 445 Albert Street East, Sault Ste. Marie P6A 2J9 (705) 949-4640
Timmins: 83 Algonquin Blvd. West, Timmins P4N 2R4 (705) 268-3222
Welland: 637 Niagara Street North, Welland L3C 1L9 (905) 384-9845
Windsor: 250 Windsor Avenue, 6th Floor, Windsor N9A 6V9 (519) 254-2546

Government Funding

The following is not intended as a comprehensive listing of programs for which government funding is available. Contact your local offices of MOEE and Environment Canada for further information.

Ontario Programs

Industrial Waste Diversion Program
The goal of this Ontario Ministry of Environment and Energy program is to divert Institutional, Commercial and Industrial hazardous and non-hazardous waste from disposal through the 3Rs.

Eligible projects include:
- New facilities/processes for the reduction, reuse, and recycling of industrial, commercial and institutional wastes;
- Modifying existing processes, equipment or operations to divert significant quantities of waste from disposal; and
- Demonstration of technology and pilot/research projects aimed at implementing new waste diversion methods, including process or equipment evaluations.

Eligible Costs
- Capital costs - up to a maximum of 50% for eligible equipment and its associated installation and commissioning costs.
- Research/demonstration costs - up to 100% of eligible costs of a project that deals with applied research, demonstration and evaluation of a technology or process which results in the diversion of waste.

For more information contact:
Ministry of Environment and Energy
Program Development Branch
Program Support Section
40 St. Clair Avenue West, 11th Floor
Toronto, Ontario M4V 1M2
Tel.: 1-800-268-4483
(416) 314-7878
Fax: (416) 314-4128

Ministry of Environment and Energy Regional Offices:
Kingston (613) 549-4000
London (519) 661-2200
Sudbury (705) 675-4501
Thunder Bay (807) 475-1205
Hamilton (905) 521-7640
Toronto (416) 424-3000

Applied Pollution Prevention Program

This program funds initial demonstration projects for technologies that prevent or reduce pollution at source.

Eligible projects include:
- research and development of innovative products and processes;
- development and testing of equipment prototypes
- pilot-scale equipment refinement and adaptation;
- full-scale field trials and demonstration projects

This program provides 50% of the project funding up to a maximum of $500,000 per year per project.

For more information contact:
Ministry of Environment and Energy
Environmental Technology Unit
Research and Technology Section, Fiscal Planning and Information Management Branch
135 St. Clair Avenue West, 11th Floor
Toronto, Ontario M4V 1P5
Tel.: (416) 323-4649
Fax: (416) 323-4322

Environmental Research Program

The Ministry of Environment and Energy funds well-defined research projects to develop solutions to the problems which the MOEE has identified as having the highest priority.

Eligible projects would be identified from the following research areas:
- air and water quality
- waste management
- analytical instrumentation
- environmental socio-economics
- multi-media contaminants and biotechnology
- 3Rs
- risk assessment
- acid mine drainage
- zebra mussel control

For more information contact:
Ministry of Environment and Energy
Research and Technology Section, Fiscal Planning and Information Management Branch
135 St. Clair Avenue West, 11th Floor
Toronto, Ontario M4V 1P5
Tel.: (416) 323-4649
Fax: (416) 323-4322

Federal Programs

Environmental Innovation Program (EIP)

Funded under the federal government's Green Plan, the Environmental Innovation Program is designed to promote innovative Canadian environmental R & D outside government. Proposals will be considered which directly support the goals and objectives of the Green Plan:
- clean air, water and land;
- sustainable use of renewable resources;
- protection of our special spaces and species;
- preserving the integrity of our North;
- global environmental security;
- environmentally-responsible decision making at all levels of society; and
- minimizing the impacts of environmental emergencies

Proposals must meet the following criteria:
- relevance to the Green Plan
- uniqueness
- environmental scientific merit and technical feasibility
- sponsorship
- funding

Detailed information on EIP, including a copy of program guidelines and Canada's Green Plan, can be obtained at your local Government Services Office or by contacting:
Program Officer
Environmental Innovation Program
Science and Professional Services Directorate - 1201 Phase III Place du Portage
Government Services Canada (formerly Supply & Services Canada)
Hull, Quebec K1A 0S5
Tel: (819) 956-1774 or toll free 1-800-563-3518

Federal Business Development Bank

The creation and development of small to medium-sized business is promoted through term loans, loan guarantees, venture capital, and a broad range of management training, counselling, and planning services. For more information call: (416) 973-1144 or Fax (416) 973-0032.

St. Lawrence Action Plan

Environment Canada, through the Technology Development Branch at its St. Lawrence Centre funds projects to develop or demonstrate technology to reduce the discharge of toxic waste from targeted industries along the St. Lawrence River. Projects are funded to 50% of the eligible costs to a maximum contribution of $1 million.

For more information contact:
Director
St. Lawrence Centre
Montreal, Quebec
(514) 283-9274

Environmental Technology Commercialization Program

The objective for this program is to accelerate the transfer, development, demonstration, and commercialization of environmental technologies through cooperative arrangements with universities, research institutions and the private sector. Assistance is provided by sharing expenses in projects that demonstrate, for the first time, the use of new environmental technologies which have prospects of commercialization. Successful technology demonstration projects may receive assistance of up to 50% of the eligible costs to a maximum contribution of $5 million.

For more information contact:
Program Manager
Environmental Affairs Branch
Industry, Science and Technology Canada
235 Queen Street
Ottawa, Ontario
K1A 0H5
Tel.: (613) 954-3242
Fax : (613) 954-3430

Industrial Research Assistance Program (IRAP)

The goal of the IRAP program is to promote and assist competitiveness for Canadian companies through technology development and/or acquisition. Projects are typically of two types:

1) Technology Enhancement
These projects include feasibility studies, small scale research and development, and problem solving. Funding is up to 50% of eligible costs and a maximum of $15,000 per project.

2) Research and Development
These are larger higher risk projects which improve technological competitiveness and include applied research and development where there is strong potential for commercialization. Funding is up to 50% of eligible costs and a maximum of $350,000.

To obtain further information, Ontario residents contact:
National Research Council of Canada - IRAP
(416) 973-4484

To determine regional offices outside of Ontario, contact:
Technological Assessment National Coordination Office
National Research Council of Canada - IRAP
(613) 993-1790

Development and Demonstration of Resource and Energy Conservation Technology (D=>RECT) Program

Environment Canada is interested in finding new energy-efficient recycling technologies to recover or reduce the millions of tonnes of waste thrown away each year. Private corporations and agencies, as well as municipal authorities, proposing to demonstrate innovative methods, procedures, processes, or equipment can apply for partial funding. D=>RECT may contribute up to 50% of the total estimated costs (but usually 25 to 30% to a maximum of $200,000/yr).

For further information, please contact:
D=>RECT Program
Technology Development Branch
Conservation and Protection
Environment Canada
Hull, Quebec
K1A 0H3
Telephone: (819) 953-7827

Technical Assistance/Training/Information

The following is not intended as a comprehensive listing of programs for which government assistance is available. Contact your local offices of MOEE and Environment Canada for further information.

Ontario Programs

Ontario Waste Management Corporation (OWMC)

Ontario Waste Management Corporation has an ongoing program to help Ontario industry reduce, reuse or recycle hazardous and liquid industrial wastes. Intensive waste management assistance is provided by OWMC Waste Management Specialists with technical, regulatory, and end-use market expertise. In addition, comprehensive one-day workshops on waste minimization are offered each year in a number of locations throughout Ontario. OWMC publishes the Waste Reduction Bulletin three times a year. The Waste Reduction Bulletin is a periodical for Ontario industry promoting hazardous waste reduction. Each year, OWMC recognizes organizations in Ontario that have significantly reduced its hazardous waste through OWMC's Outstanding Waste Reduction Performance Awards.

For further information contact:
Waste Reduction Group
Ontario Waste Management Corporation
2 Bloor St. West, 11th Floor
Toronto, Ontario
M4W 3E2
Tel.: (416) 923-2918
1-800-268-1178
Fax: (416) 923-7521

Pollution Prevention Office (PPO)

The goal of the Pollution Prevention Office is to transform the Ontario Ministry of Environment and Energy primarily into a pollution prevention, conserver driven organization, inspired by a multi-media ecosystem perspective. The Office works to ensure that pollution prevention is incorporated into Ontario's programs and policies.

The Pollution Prevention Office operates under a 3-pronged strategy: flagship programs, program realignment and cooperative leadership in external programs.

The office administers the Pollution Prevention Pledge Program (a voluntary industry challenge-recognition program), negotiates sector agreements, coordinates multi-dimensional policy and project development, and promotes pollution prevention.

PPO promotional initiatives includes 4 pollution prevention awards each year for small, medium and large businesses, facilities and organizations that promote pollution prevention. The PPO has also published the "Pollution Prevention Planning Guidance Document and Workbook".

For more information contact:

Technical inquiries:
Pollution Prevention Office
Ontario Ministry of Environment and Energy
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
Tel.: (416) 314-4135
Fax: (416) 323-7930

Publications, Program Materials:
Public Information Centre
Ontario Ministry of Environment and Energy
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
Tel.: (416) 323-4321
1-800-565-4923
Fax: (416) 323-4564

Ontario's Green Industry Strategy

The Green Industry Strategy works to forge partnerships with industry, financial groups, communities, environmentalists and labour to capture the economic opportunities stemming from the growing demand for environmentally-friendly services and technologies. Some of the projects and programs within the Strategy are listed below.

The Green Industrial Analysis/Retrofit Project

This project helps industry manage their energy and water use more efficiently, reduce and recycle solid waste, and minimize liquid and gaseous emissions. The project covers the following three phases: site assessment, feasibility study, and retrofit implementation. For more information contact:

Program Co-ordinator, Industry Programs
Ontario Ministry of Environment and Energy
14th Floor, 56 Wellesley St. W.
Toronto, Ontario
M7A 2B7
Tel.: (416) 327-1440
Fax: (416) 327-1261

Environment Business Development Unit

This unit helps firms to commercialize environmental technologies, services and products. It provides business planning and marketing information and assists and stimulates the growth of Ontario companies supplying environmentally-friendly goods and services.

For more information contact:
Business Development Unit
Ontario Ministry of Environment and Energy
135 St. Clair Avenue West, 5th Floor
Toronto, Ontario M4V 1P5
Tel.: (416) 323-4452
Fax: (416) 323-4437

Green Communities Initiative

The Green Communities Initiative offers Ontario communities assistance to develop local integrated approaches to energy and water.

For more information contact:
Community Outreach Programs
Ontario Ministry of Environment and Energy
14th Floor, 56 Wellesley St. W.
Toronto, Ontario
M7A 2B7
Tel.: (416) 327-1478
Fax: (416) 327-1514

ON-SITE

ON-SITE is an industry-government partnership that provides job experience to unemployed professionals and helps employers address the key environmental, energy and quality management challenges of the '90s. It is sponsored by the Canadian Manufacturers' Association (CMA) and managed by Energy Pathways Inc., an Ottawa-based environmental services firm that pioneered the concept in 1983. (ON-SITE operates in Ontario, Quebec and New Brunswick).

ON-SITE places qualified, unemployed individuals "on-site" in companies, institutions and municipalities to assist with:

- environmental management
- reduction of solid waste
- reduction and management of hazardous waste
- energy management
- occupational health and safety
- ISO 9000 assessment and implementation (quality management system)

For more information, contact:

ON-SITE
c/o Energy Pathways Inc.
500-251 Laurier Avenue West
Ottawa, Ontario K1P 5J9
Tel: (613) 235-5303
Fax: (613) 235-2190

ON-SITE
Energy Pathways Inc.
250 The Esplanade, Suite 305
Toronto, Ontario M5A 1J2
Tel: (416) 360-1323
Fax: (416) 360-1706

Ontario Waste Exchange (OWE)
A project of OWMC, the Ontario Ministry of the Environment and Energy and ORTECH International, the Ontario Waste Exchange helps industries minimize their waste generation and find uses and users for their special wastes. Established in 1984, the OWE is fully funded by MOEE and OWMC.

For more information contact the Ontario Waste Exchange:
ORTECH International
2395 Speakman Drive
Mississauga, Ontario
L5K 1B3
(905) 822-4111 ext. 358

Ontario Centre for Environmental Technology Advancement (OCETA)
The business plan for the new $10 million Ontario Centre for Environmental Technology Advancement is complete and under review by the federal and provincial governments. Approval is expected before the end of 1993. The new centre will be located in a Toronto Economic Development Corporation (TEDCO) facility in the Toronto harbour.

Federal Programs

Great Lakes Pollution Prevention Centre
The Great Lakes Pollution Prevention Centre promotes the development and implementation of pollution prevention activities in the Great Lakes basin. The Centre offers customized training seminars, technical assistance, access to technical information through electronic databases, and makes available technical documents, books, reports and periodicals. Summaries of success stories in pollution prevention are prepared and presented in case study format. The Centre also organizes conferences and workshops and publishes a newsletter, "At the Source", quarterly.

For more information contact:
Great Lakes Pollution Prevention Centre
265 North Front Street
Suite 112
Sarnia, Ontario
N7T 7X1
Tel.: (519) 337-3423
1-800-667-9790 (in Ontario)
Fax: (519) 337-3486

Institute for Environmental Chemistry (IEC)
The Institute for Environmental Chemistry (IEC) of the National Research Council assists emerging environmental companies to test and develop their technologies. The Institute is a a research leader in the areas of polymer science, electrochemical technology, fine particle technology, separation science, atmospheric chemistry, and process technology. To develop your collaborative research contact:

Institute of Environmental Chemistry (IEC)
National Research Council Canada
Montreal Road
Ottawa, Ontario
K1A 0R6
Tel.: (613) 990-6618
Fax: (613) 957-8231

Recycling Advisors

Region of Durham: ICI Waste Reduction Facilitator (416) 668-7721
Essex/Windsor: Waste Reduction Specialist (519) 776-6441
Guelph: Waste Management Coordinator (519) 837-5604
Region of Haldimand-Norfolk: Waste Reduction Coordinator (519) 587-4911
North Simcoe: Waste Reduction Coordinator (705) 526-6900
Peterborough: Solid Waste Coordinator (705) 742-7771
Stratford: Waste Reduction Coordinator (519) 271-0250 ext. 279
Metro Toronto: Recycling Advisor (416) 392-4200
Lindsay: Environmental Coordinator (705) 324-6171
Region of Waterloo: Manager of Waste Reduction (519) 885-9776
London: Recycling Advisor (519) 661-5411
Region of Peel: Recycling Advisor (905) 791-9400 ext. 4767

Selected Reading List

Practical Guide for Sampling Wastes and Industrial Processes
by Ontario Waste Management Corporation, Toronto, 1993

Contains step-by-step procedures for sampling wastes and industrial processes in regulatory and non-regulatory situations. Topics include planning, establishing appropriate locations, process and/or waste characteristics at these locations, strategies, quality assurance, preservation, sampling equipment and container selection, determining the number of samples to take, and liaison with the laboratory. Material has been condensed into a flow chart format with accompanying text.

Profit from Pollution Prevention: a Guide to Industrial Waste Reduction & Recycling
by Monica E. Campbell and William M. Glenn, Toronto: Pollution Probe Foundation, c1982

Documents pollution prevention success stories of firms that have turned waste products into financial assets. Industries profiled include: dry cleaning; electroplating; fly ash, sulphur and other solid wastes; food processing; oil; paints and coatings; photography; plastics; printing; pulp and paper; solvents; tanning; textiles. Also describes various waste recovery, treatment and disposal technologies.

Profit from Pollution Prevention: a Guide to Waste Reduction and Recycling in Canada (2nd edition, revised)
by Glenn Munroe, William P. Bradley, Fay Neuber; with the assistance of William M. Glenn and Randee L. Holmes, Toronto: Pollution Probe Foundation, c1990

A general guide that describes how a company can develop a program for reducing its wastes. Revised from Profit from Pollution Prevention: a Guide to Industrial Waste Reduction & Recycling, c1982.

Pollution Prevention Planning: Guidance Document and Workbook
by Ontario Ministry of Environment and Energy
Toronto, May 1993

Explains how to develop, implement, and maintain a pollution prevention plan, measure progress, conduct an economic analysis of pollution prevention projects, design environmentally compatible products, etc. Includes worksheets and pollution prevention checklists.

Regulation 347 under the Environmental Protection Act (General -Waste Management Regulation)
Revised Regulations of Ontario 1990 as amended by O. Reg. 183/92; 240/92; 501/92; and 555/92

This is the principle regulation governing the management of waste in Ontario. All those involved with wastes covered by this regulation should be aware of its provisions.

Proven Profits from Pollution Prevention: Case Studies in Resource Conservation and Waste Reduction
by Donald Huisingh, Larry Martin, Helene Hilger, Neil Seldman
Washington, D.C.: Institute for Local Self-Reliance, c1986

Presents waste reduction opportunities in various sectors, including: textile mill products; chemicals and allied products; fabricated metal products; electrical and electronic equipment, etc.

Cutting Chemical Wastes: What 29 Organic Chemical Plants are Doing to Reduce Hazardous Wastes
by David Sarokin, Warren Muir, Catherine Miller, Sebastian Sperber
New York: Inform Inc., 1985

Investigates 29 organic chemical plants to discover what steps are being taken to reduce wastes; what impact these practices have on total plant wastes; and what managerial, economic, and/or regulatory factors are stimulating or impeding hazardous waste reduction efforts.

Profiting from Waste Reduction in Your Small Business: a Guide to Help You Identify, Implement and Evaluate an Industrial Waste Reduction Program
by David Wigglesworth, Anchorage, Alaska: Alaska Health Project, 1988

Intended as a guidance manual to help businesses take the first step toward evaluating waste reduction opportunities and to build awareness of the benefits of waste reduction.

Audit and Reduction Manual for Industrial Emissions and Wastes
United Nations Environment Programme, Industry and Environment Office (UNEP/IEO)
Paris: UNEP, c1991

Modelled on OWMC's Industrial Waste Audit and Reduction Manual. Includes three case studies on beer production, leather manufacture, and printed circuit board manufacture.

Techniques for Industrial Pollution Prevention: a Compendium for Hazardous and Nonhazardous Waste Minimization
by Michael R. Overcash, Chelsea, Michigan: Lewis Publishers Inc., c1986

Describes successful waste minimization schemes in various industrial sectors, including agriculture and food, construction materials, chemical manufacturing, metallurgy, surface treatment, textiles, tanneries, and wood products.

Waste Reduction for Pollution Prevention
by P.N. Cheremisinoff and L.M. Ferrante
Northbrook, IL: Pudvan Publishing Co. Inc., c1989

An overview of waste minimization processes and technologies.

Facility Pollution Prevention Guide
by United States Environmental Protection Agency, Office of Solid Waste and Risk Reduction Engineering Laboratory, Cincinnati, Ohio, May 1992

Describes how to establish, evaluate, adjust, and maintain a company-wide pollution prevention program. Includes assessment worksheets, sources of additional information, examples of evaluative methods, and a glossary. Supersedes the Waste Minimization Opportunity Assessment Manual (1988).

Guides to Pollution Prevention
by United States Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, Ohio

These Guides, published individually, provide an overview of processes and operations that generate waste and present options for minimizing waste generation through source reduction and recycling. Industries include: paint manufacturing; printed circuit board manufacturing; pesticide formulating industry; fabricated metal products; automotive refinishing; automotive refinishing; commercial printing; fibreglass-reinforced and plastics industry; marine maintenance and repair; pharmaceutical industry; photoprocessing; and selected hospital waste streams.

Waste Audit Studies
by California Environmental Protection Agency, Department of Toxic Substances Control
Sacramento, Calif.

Full scale assessments of specific industries, published individually, that show where waste minimization methods can be most effective. Studies include the following industries: general medical and surgical hospitals; building construction industry; commercial printing; drug manufacturing and processing; fabricated metal products; commercial and industrial mechanical equipment repair; non-agricultural pesticide application; thermal metal working; stone, clay, glass, and concrete products; aerospace and electronics industry.

Waste Reduction Assistance Program On-Site Consultation Audit Reports
by Alaska Health Project, Anchorage, Alaska

Individually published reports describing the processes used and wastes produced by particular businesses. These include: a dairy foods plant; manufacturing / distributing company; an electroplating shop; a dry cleaner; an aviation maintenance facility; an automotive repair shop; a photofinishing shop; a printing company; an automobile body repair and paint shop; and a fur dressing tannery.

Waste Minimization - Issues and Options: Volume 2
by Versar Inc. and Jacobs Engineering Group for United States Environmental Protection Agency, Office of Solid Waste and Emergency Response
Washington, D.C.: US EPA, October 1986

Contains 22 exploratory studies of various industrial processes and practices known to generate or influence the generation of hazardous wastes and their source reduction practices. Includes, among other processes: electroplating; inorganic pigments manufacture; metal surface treatment; paint manufacturing; petroleum refining; metal parts cleaning; process equipment cleaning, etc.

Hazardous Waste Minimization Handbook
by Thomas E. Higgins, Chelsa, Michigan: Lewis Publishers Inc., 1989

Outlines a method for companies to use to establish a waste minimization program and describes specific waste reduction techniques applied by a number of industries, including metal working operations, solvent cleaning and degreasing, metal plating and finishing, and painting and coating.

Hazardous Waste Minimization Manual for Small Quantity Generators
by Center for Hazardous Materials Research, University of Pittsburgh Applied Research Center
Pittsburgh, October 1989 (rev. ed.)

Describes how to conduct a waste audit and includes industry-specific and waste-specific minimization practices.

New York State Waste Reduction Guidance Manual
Prepared by ICF Technology Incorporated for New York State Department of Environmental Conservation
New York, March 1989

Describes how to start and sustain waste reduction within your company, including waste reduction audits and process-specific techniques.

Pollution Prevention Case Studies Compendium
by United States Environmental Protection Agency, Office of Research and Development, 1992

Examines a variety of facilities, including hospitals, school boards, chemical businesses, and military installations, describing technology or process changes, waste reduction, costs, etc.

Waste Minimization Case Studies
by Government Institutes, Rockville, MD, 1991

A collection of 68 case studies describing the pollution prevention programs of small and large companies. Includes industry-specific examinations, including paint manufacturing, fabricated metals, commercial printing, etc.

Appendix A

Sampling for a Waste Audit

Sampling of process and waste streams plays an important role in a waste audit. But the physical and chemical measurements of a process or waste stream are only valuable in determining material balance if the sample is representative of that stream.

There are many variables involved in sampling process and waste streams: the composition of the waste streams themselves, the sampling locations (drums, pipes, tanks, pits, lagoons, etc.) and the sampling equipment. Thus, professional judgment and common sense are required to ensure that a sample is truly representative of the process or waste stream being sampled.

A representative sample is one that encompasses all aspects of the waste, including particle size, concentration of constituents and effects of layering. The sample should be taken in such a way that it truly reflects the original material, since the quality of the analytical results generated from the samples is only as high as the quality of the sampling effort itself.

While a laboratory will be able to test any sample submitted to it, an unrepresentative sample can lead to errors in an audit or, at the very least, the waste of the cost and effort that has gone into the sampling effort and analyses.

Sampling Objective

Why is sampling being performed? This fundamental question must be answered to ensure that all involved understand the purpose of the exercise and that the design of a sampling plan addresses the goals of the waste audit.

Background Information

Thorough knowledge of the waste/process stream is useful prior to designing the sampling plan. Background information can be obtained from material safety data sheets, previous analyses, in-house knowledge of the process, interviews with key people, generator registration and manifest information and hazardous material reference texts.

Phase Determination and Homogeneity/Heterogeneity

Observe the number of phases that make up the waste. This is the number of physically distinct layers in the waste. A one-phase waste will be of the same physical state throughout (e.g. liquids such as spent plating baths and waste oil). These wastes are usually homogeneous, in that they have a uniform composition.

A two-phase waste can be a combination of physical states, such as liquid paint with paint solids settled out. It can also consist of wastes in the same physical state with two distinct layers, such as a watery waste mixed with a liquid organic waste (e.g. oil and water). Wastes containing two or more phases are heterogeneous, in that they do not have a uniform composition.

Physical State

The physical state of the waste should be matched to one of the definitions below. If the waste has more than one phase, the physical state of each phase should be recorded.

1. Liquid: Flows freely, like water.

2. Solid: Does not appear to flow under moderate stress.
   a) Powder: A solid that exists as smaller particles; a small grained powder resembling sand, a large grained powder resembling pellets.
   b) Hard Packed: The material is not easily broken down.

3. Slurry: A thin mixture of a liquid and a material that will not dissolve in the liquid (such as clay and water). The material will flow to a certain extent.
4. Sludge: A thick mixture of a liquid and a material that will not dissolve in the liquid. The material will not flow easily if at all.

Storage Location and Production Factors

Waste storage locations and process sampling sites need to be identified. It is also important to know if there are any production factors that could affect the sampling process. These fall into three categories:

1) Type of Process: Batch vs. Continuous
A batch process is one that generates the product as one lot whereas a continuous process generates the product on an ongoing basis.

If the process to be sampled operates in a batch mode, it is important to have some idea as to the variation that may exist between batches. If only one of the batches is sampled, how representative is that of the overall situation?

2) Changes in Raw Materials or Sources of Materials:
While not usually recognized as a problem area, a change in raw material may introduce a new constituent to the process due to impurities in the new raw material.

3) Operating Conditions:
Samples taken during differing operating conditions often generate very different analytical results. It is important to establish operating variables and to sample when the system is operating in its most "normal" mode.

Sampling Strategy

Choosing the most appropriate sampling strategy will depend on the specific situation and the level of background information obtained. The sampling strategies that follow will handle most general situations but specific situations sometimes require combinations of strategies or variations on a strategy. We would advise the reader to refer to the OWMC Practical Guide for Sampling Wastes and Industrial Processes or to seek professional assistance if the scenario does not easily fit into one of the following descriptions.

Simple Random Sampling: The term "random" refers to the probability based approach that uses a random numbers table to decide sampling locations. In this strategy, any portion of the stream has an equal probability of being sampled. The purpose of this approach is to ensure that a representative sample is obtained without a bias being introduced. This approach is useful in determining average levels when little is known about the area to be sampled.

Systematic Random Sampling: This strategy involves selecting a random starting location or starting time for the first sample and then sampling at regular intervals from that point forward. This strategy is most commonly used when there are systematic variations in the composition of the material. One such example would be batch production of a variety of different products over a period of time.

Stratified Random Sampling: If distinct layers have been identified in the waste, it is necessary to treat the layers as if they were separate and establish a randomized sampling pattern for each.

Convenience Sampling: This is the least preferred sampling strategy and should only be used when conditions are such that no other strategy is feasible. Convenience sampling is used when the site is very inaccessible or when there are safety factors that prevent a sample from being easily obtained. Try to locate sampling points where some degree of randomness can be incorporated into the design. The bottom line with this strategy is to take a sample wherever and whenever you can.

Number of Samples

The planners of the sampling program determine what number of samples is reasonable and which inputs and outputs require testing. Often budget plays a major role in defining the maximum number of samples that can be taken.

Determining the Type of Sample to Take

There are two types of sample that may be taken; grab or composite.
A grab sample is taken at a discrete point in time from one specific sampling location. It represents the static conditions of that particular sampling site for the time at which the sample was taken. It can be a representative sample if taken using the most appropriate strategy.

A composite sample is composed of two or more grab samples of equal size that have been combined. They may be from the same location but taken at different times, or from different sampling locations within the same process area, e.g. a lagoon. If the purpose of the sampling is to give an average concentration over an area or time then all the discrete grab samples can be combined into a composite sample. Composite sampling is often used for sewer testing where a grab sample is taken every hour for 24 hours and all are combined to produce one sample for analysis which represents the average discharge for the plant over that 24 hour period.

The main disadvantage to composite sampling is that all information on peak levels from the grab samples is lost when the samples are combined. Also, chemical reactions may occur on mixing which may cause the sample to be unrepresentative of the original sampling site or to present a safety risk.

If a composite sample is required, it is preferable to take the grab samples to a laboratory where exact proportions of the grab samples can be combined to produce an accurate composite in controlled and safe conditions, while retaining portions of the original grab samples.

Additional help

Detailed information on sampling procedures, techniques and equipment is contained in the OWMC Practical Guide for Sampling Wastes and Industrial Processes. This guide is sold separately by OWMC.

We welcome your response

Comments and Suggestions

Your comments about this manual would be greatly appreciated. Please provide your comments and suggestions in the space below and mail to:

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All those who provide comments which are incorporated in the next edition will be sent a complimentary copy when it is published.

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