Monographs on Refinery Environmental Control— Management of Water Discharges

Design and Operation of Oil–Water Separators

API PUBLICATION 421
FIRST EDITION, FEBRUARY 1990

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

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FOREWORD

The *Monographs on Refinery Environmental Control* consist of four series—*Management of Emissions to Air, Management of Water Discharges, Management of Solid Wastes,* and *Management of the Subsurface Environment.* The monograph series are ongoing projects of the Committee on Refinery Environmental Control of the API Refining Department and are intended to be used by engineers responsible for the design, construction, operation, and maintenance of disposal systems for wastes generated in refineries.

This monograph provides design guidance for gravity-type oil–water separators for use in petroleum refineries, provides practical advice on solving operating problems and improving separator performance, and presents information on performance of existing refinery separators.

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Suggested revisions are invited and should be submitted to the director of the Refining Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Design and Operation of Oil–Water Separators

SECTION 1—GENERAL

1.1 Introduction

The purpose of this monograph is to provide design guidance on gravity-type oil–water separators for use in petroleum refineries, to provide practical advice on solving operating problems and improving separator performance, and to present information on the performance of existing separators.

This monograph deals solely with gravity-type oil–water separators, that is, those that rely on differences in specific gravity to separate oil globules from a wastewater stream. Two types of oil–water separators are covered in this monograph:

a. The conventional, rectangular-channel unit.
b. The parallel-plate separator.

Note: Throughout this monograph, the term *conventional oil–water separator* is used in place of the term *API separator* and refers to rectangular-channel units designed in accordance with the criteria published earlier by API. The term *API separator* has become almost a generic term, sometimes used incorrectly to refer to any gravity-type oil–water separator.

Historically, the design of conventional oil–water separators was based on criteria developed from a 3-year, API-funded research study initiated in 1948 at the Engineering Experiment Station at the University of Wisconsin [1]. Since then, numerous oil–water separators based on the API-developed design criteria have been designed and put into operation throughout the petroleum industry. The criteria were developed as voluntary guidelines for designing conventional oil–water separators. Many other separators based in part on the API-developed design criteria have been adapted for a variety of other industrial wastewater treatment applications.

This monograph retains pertinent information from Chapters 5 and 6 of the 1969 edition of the *API Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* and incorporates the recent findings of a literature review and 1985 survey of refinery separators. Data from this survey of the design and operation of oil–water separators have been incorporated in this monograph.

Although the theory of oil–water separators is briefly discussed, the emphasis of this monograph is on practical guidance for those involved in the design or operation of oil–water separators.

1.2 Background

A refinery wastewater stream may contain oil in three major forms: free, emulsified, and dissolved. Some pertinent features of each of these are briefly discussed below:

Free oil is in the form of discrete oil globules of a size sufficient so that the globules can rise as a result of buoyant forces and form an oil layer on top of the water. Under proper quiescent flow conditions, free oil can be removed by gravity separation. This removal is a function of residence time, differences in specific gravity and temperature, and the stability of the emulsion. Some coarse oily solids have a specific gravity greater than 1.0 and will settle to the bottom of a separator. Most of the oil and associated fine solids in refinery wastewater have a specific gravity of less than 1.0 and will rise to the water's surface.

Emulsified oil is in the form of much smaller oil droplets or globules with a diameter of less than 20 microns (mostly in the 1–10-micron range). These globules form a stable suspension in the water as a result of the predominance of interparticle forces over buoyant forces. The presence of particulates also contributes to emulsion formation. Regardless of how long a true oil–water emulsion stands under quiescent conditions, a separate oil phase will not form. Emulsified oil may be removed by chemical addition and coalescing or by flotation but not by gravity separation alone.

Dissolved oil is the petroleum fraction that forms a true molecular solution with water. Dissolved oil cannot be removed by gravity separation; further wastewater treatment (for example, biological treatment) is necessary if removal of dissolved oil is required.

The fraction of oil that is removable from a wastewater stream by gravity separation is affected by the type of oily material present. The method of measuring oil concentration can also affect the apparent efficiency of removal. Conventional oil–water separators remove only free oil; stable emulsions and dissolved oil require additional treatment.

1.3 Basic Theory

In essence, an oil–water separator is a chamber designed to provide flow conditions sufficiently quiescent so that globules of free oil rise to the water surface and coalesce into a separate oil phase, to be removed by mechanical means.

Oil–water separation theory is based on the rise rate of the oil globules (vertical velocity) and its relationship to the surface-loading rate of the separator. The rise rate is the velocity at which oil particles move toward the separator surface as a result of the differential density of the oil and the aqueous phase of the wastewater. The surface-loading rate is the flow rate to the separator divided by the surface area of the separator. In an ideal separator, any oil globule with a rise rate greater than or equal to the surface-loading rate will reach the separator surface and be removed. An ideal separator is assumed to have no short circuiting, turbulence, or eddies. The required surface-loading rate for removal of a specified size of oil droplet can be determined from the equation for rise rate. The derivations of the basic equations for oil–water separator design are given in Appendix A. The mathematical relationship for the rise rate is provided by a form of Stokes' Law:

$$V_t = (g/18\mu)(\rho_w - \rho_o)D^2 \qquad (1)$$

Where:

V_t = vertical velocity, or rise rate, of the design oil globule, in centimeters per second.
g = acceleration due to gravity
= 981 centimeters per second squared.
μ = absolute viscosity of wastewater at the design temperature, in poise.
ρ_w = density of water at the design temperature, in grams per cubic centimeter.
ρ_o = density of oil at the design temperature, in grams per cubic centimeter.
D = diameter of the oil globule to be removed, in centimeters.

The vertical velocity of an oil globule in water depends on the density and diameter of the oil globule, the density and viscosity of the water, and the temperature. The oil globule's vertical velocity is highly dependent on the globule's diameter, with small oil globules rising much more slowly than larger ones. It has been determined from the API research mentioned above that, using the example design procedures described in this monograph, oil globules with a diameter greater than or equal to 0.015 centimeter (150 microns) can be expected to be removed effectively in a gravity separation chamber without plates.

With the oil globule diameter fixed at 0.015 centimeter, Equation 1 can be simplified (see Appendix A) to yield, in English units,

$$V_t = 0.0241\frac{S_w - S_o}{\mu} \qquad (2)$$

Where:

V_t = vertical velocity of the oil globule, in feet per minute.
S_w = specific gravity of the wastewater at the design temperature (dimensionless).
S_o = specific gravity of the oil present in the wastewater (dimensionless, not degrees API).
μ = absolute viscosity of the wastewater at the design temperature, in poise.

Procedures for determining specific gravities for oil and wastewater and for wastewater viscosity are given in 2.1.1.

Equation 2 embodies two fundamental principles that should always be kept in mind when designing and operating oil–water separators:

a. The performance of the separator will be highly dependent on the difference between the specific gravity of the water and that of the oil. the closer the specific gravity of the oil is to that of the water, the slower the oil globules will rise.
b. Since the oil globules' rise rate is inversely proportional to the viscosity of the wastewater, oil globules will rise more slowly at lower temperatures.

Both of these factors play an important role in selecting design conditions in the design procedure for oil–water separators presented in 2.1.

For those further interested in the theoretical aspects of particle settling, a derivation of Equations 1 and 2 is presented in Appendix A.

1.4 Application

As stated above, oil–water separators are designed to remove free oil only. If emulsified or dissolved oil is present, one cannot expect an oil–water separator to remove it, and additional downstream treatment may be required. A principal function of the oil–water separator is to remove gross quantities of free oil before further treatment. In this capacity, the oil–water separator protects more sensitive downstream treatment processes from excessive amounts of oil. Since separator skimmings are typically recycled, and oil not recovered can end up as sludge, efficient recovery results in minimization of waste.

The performance of gravity oil–water separators varies with changes in the characteristics of the oil and wastewater, including flow rate, specific gravity, salinity, temperature, viscosity, and oil-globule size. Performance is also a function of design and operational constraints and of the analytical methods used to measure performance. The API survey data included in this monograph reflect the large amount of variability that is a result of these many factors. However, the survey data indicate that increasing separator size, as measured by surface-loading rate, results in improved performance, as measured by effluent oil and grease. Unit design needs to take into account the impact on downstream oil removal processes (for example, dissolved-air flotation) to determine whether incremental improvements in performance can be justified.

Parallel-plate separators are based on a newer technology. They require less space than do conventional oil–water separators and are theoretically capable of achieving lower concentrations of effluent oil. Petroleum industry data are insufficient to conclude that parallel-plate units offer overall superior performance.

There are petroleum industry applications in which oil–water separators are the only end-of-pipe treatment provided. These are usually cases in which the only effluent restrictions specified are for oil or suspended solids and the wastewater in question consistently contains sufficiently low amounts of emulsified and dissolved oils. In some applications, the oil–water separator is provided as a protective device for containment of spills and leaks (for example, on once-through cooling water). Another example is an instance in which a stream is discharged to a publicly owned treatment works and the oil–water separator is used to ensure compliance with requirements for pretreatment of oil and grease.

It should be stressed that whenever an oil–water separator is considered for an application where it must stand alone, the amount of emulsified and dissolved oils in the wastewater stream must be properly quantified, because these oils will not be removed by the separators. More important, the design procedures in this monograph relate to refinery pretreatment of contaminated wastewater. Other applications require special consideration.

One aspect of oil–water separator design that is sometimes overlooked is that whether intended to or not, an oil–water separator also functions as a sedimentation basin. Solid particles more dense than water (for example, soil and coke particles) will tend to settle out in the separator. Provision must therefore be made to deal with the removal of settleable solids that accumulate in the separator.

1.5 Referenced Publications

The following publications are cited in this monograph:

ASTM[1]

D 445	*Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)*
D 1429	*Test Methods for Specific Gravity of Water and Brine*
D 1888	*Test Methods for Particulate and Dissolved Matter in Water*
D 3921	*Test Method for Oil and Grease for Petroleum Hydrocarbons in Water*

EPA[2]

"Standards of Performance for VOC Emissions from Petroleum Refinery Wastewater Systems" (40 *Code of Federal Regulations* Part 60, Subpart QQQ)

"Hazardous Wastes from Specific Sources" (40 *Code of Federal Regulations* Part 261.32)

SECTION 2—CONVENTIONAL OIL–WATER SEPARATORS

2.1 Design Procedures

2.1.1 GENERAL

API has established certain design criteria for determining the various critical dimensions and physical features of the separator. These are presented in a series of step-by-step design calculations. The design calculations require that certain characteristics of the wastewater be known. The more thoroughly the wastewater is characterized, the more predictable the performance of the separator will be.

2.1.2 WASTEWATER CHARACTERIZATION

2.1.2.1 General

When selecting test methods for oil in wastewater, one must consider the test objective. A number of methods are available for measuring oil, and the solids fraction includes total, filterable, settleable, and dissolved fractions. Depending on the objective, any of the methods may be applicable.

2.1.2.2 Free, Emulsified, and Dissolved Oil

The total oil and grease content of a wastewater can be determined by the U.S. Environmental Protection Agency's (EPA's) Methods 413.1, "Gravimetric Separation," and 413.2, "Infrared Spectrophotometry" [2]. Corresponding tests are Standard Methods 503A and 503B [3], published jointly by the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Pollution Control Federation (WPCF). The presence of compounds such as organic sulfur compounds can cause artificially elevated results in the oil-and-grease determination. Since oil is a complex mixture of different compounds, different test methods can give different results. These differences may not be consistent between waste streams. A summary of the applicability of these tests is given in Table 1.

An analogous ASTM method for determining oil and grease and petroleum hydrocarbons in water is D 3921. This method is similar to EPA Method 413.2, except that the valid concentration range is 0.5–100 milligrams per liter. Again, none of these methods distinguishes among free, emulsified, or dissolved oils.

Over thirty years ago, API developed an operational method for determining the emulsified and dissolved oil fraction. This method, entitled "Determination of Susceptibility to Oil Separation," is presented in Appendix B. The method employs the use of a separatory funnel to roughly

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[1] American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

[2] U.S. Environmental Protection Agency. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, D.C. 20402.

Table 1—Applicability of EPA Methods 413.1 and 413.2

Method	Concentration Range for Which the Method Is Valid[a] (milligrams per liter)	Representativeness of Analytical Results
EPA 413.1	5–1000	Measures only nonvolatile hydrocarbons (volatilizing at >70°C), excluding residue materials insoluble in Fluorocarbon 113
EPA 413.2	0.2–1000	Measures most volatile hydrocarbons in addition to heavier compounds, excluding residue materials insoluble in Fluorocarbon 113

[a] Wastewaters with oil concentrations greater than the maximum can be readily analyzed by sample dilution.

simulate the quiescent settling conditions in an oil–water separator. Wastewater is allowed to separate in the funnel for 30 minutes. Settleable solids are then withdrawn from the water phase, and the water phase is analyzed for oil and grease (the more current EPA Methods 413.1 or 413.2 or the equivalent APHA/AWWA/WPCF Standard Methods 503A and 503B should be used in lieu of older API methods.) The amount of oil and grease remaining in the water phase after the separation period represents the oil that is not susceptible to gravity separation.

The amount of free oil can be determined by analyzing a comparable wastewater sample for total oil and grease using the EPA methods or the APHA/AWWA/WPCF standard methods discussed above and subtracting the amount of oil and grease remaining in the water phase, as found using Appendix B.

It is recommended that Appendix B or a comparable method be used in designing an oil–water separator, particularly in applications where the separator must stand alone.

2.1.2.3 Solids Content

Although the primary function of an oil–water separator is to remove free oil from aqueous waste streams, the solids content of the wastewater is important in selecting separator appurtenances. Total suspended solids can be measured using Standard Method 209C [3], EPA Method 160.2 [2], or ASTM D 1888. The suspended-solids content of an oily wastewater may not be accurately measured by these methods if compounds that volatilize at temperatures at or below 103°C are present. These compounds may adsorb to particulate matter in the sample and cause difficulties in determining when the sample has been dried to constant weight.

Ignition of the dried sample from Standard Method 209C or an equivalent (following Standard Method 209D [3] or EPA Method 160.4 [2]) indicates the quantity of organic and inorganic materials present in the wastewater's solid component. Sand and similar materials may be removed by designing for low velocities in the channel preceding the main separator basin. This channel can serve as a type of grit chamber and can be beneficial in reducing solids problems within the separator itself.

Settleable solids (those that settle by gravity over a given period of time) are usually measured on a volumetric basis (see Standard Method 209E.3.a [3] or EPA Method 160.5 [2]). The results of this procedure indicate the approximate volume of settled materials that will need to be removed from the bottom of an oil–water separator. The characteristics of the settleable solids should be noted to determine how much grit is present. Based on the tradeoff between the quantity of grit in the wastewater and the amount of separator down time required for grit and sludge cleanout, a grit collector may be advisable.

2.1.2.4 Other Wastewater Characteristics

No less important than the two parameters discussed in 2.1.2.2 and 2.1.2.3 are the specific gravities of the oil and water phases and the absolute viscosity of the wastewater, which are both evaluated at the minimum design temperature. Assuming all other conditions are equal, the greater the difference in specific gravity between the water and oil phases, the better the oil–water separation will be. The specific gravity of the oily phase can be determined using the procedure given in Appendix B. The specific gravity and absolute viscosity of the wastewater should be determined experimentally where possible. In the absence of such data, values for the specific gravity and absolute viscosity of fresh and saline water can be estimated from Figures 1 and 2. ASTM D 1429 can be used to determine the specific gravity of wastewater. ASTM Method D 445 can be used to measure the viscosity of wastewater. The temperature of the wastewater can have a pronounced effect on the efficiency of the separator. In general, for the temperature range experienced in refinery wastewaters, the lower the temperature, the poorer the oil–water separation will be.

2.1.3 ESTABLISHING A DESIGN FLOW

The design flow for a conventional oil–water separator is primarily determined by two factors: the expected wastewater flow rate, and the safety factor desired to accommodate flow variations. Consideration should also be given to possible future refinery expansion. Unless flow equalization is provided upstream of the separator, the design flow should be based on the maximum flow rate attributable to current and future oil-contaminated process wastewaters and stormwater runoff. Regulatory requirements for spill control can also be a factor in identifying stormwater treatment requirements.

Uncontrolled surface runoff or storm drainage can greatly increase flow to a separator for a short period of time. In such a case, flow equalization upstream of the oil–water sep-

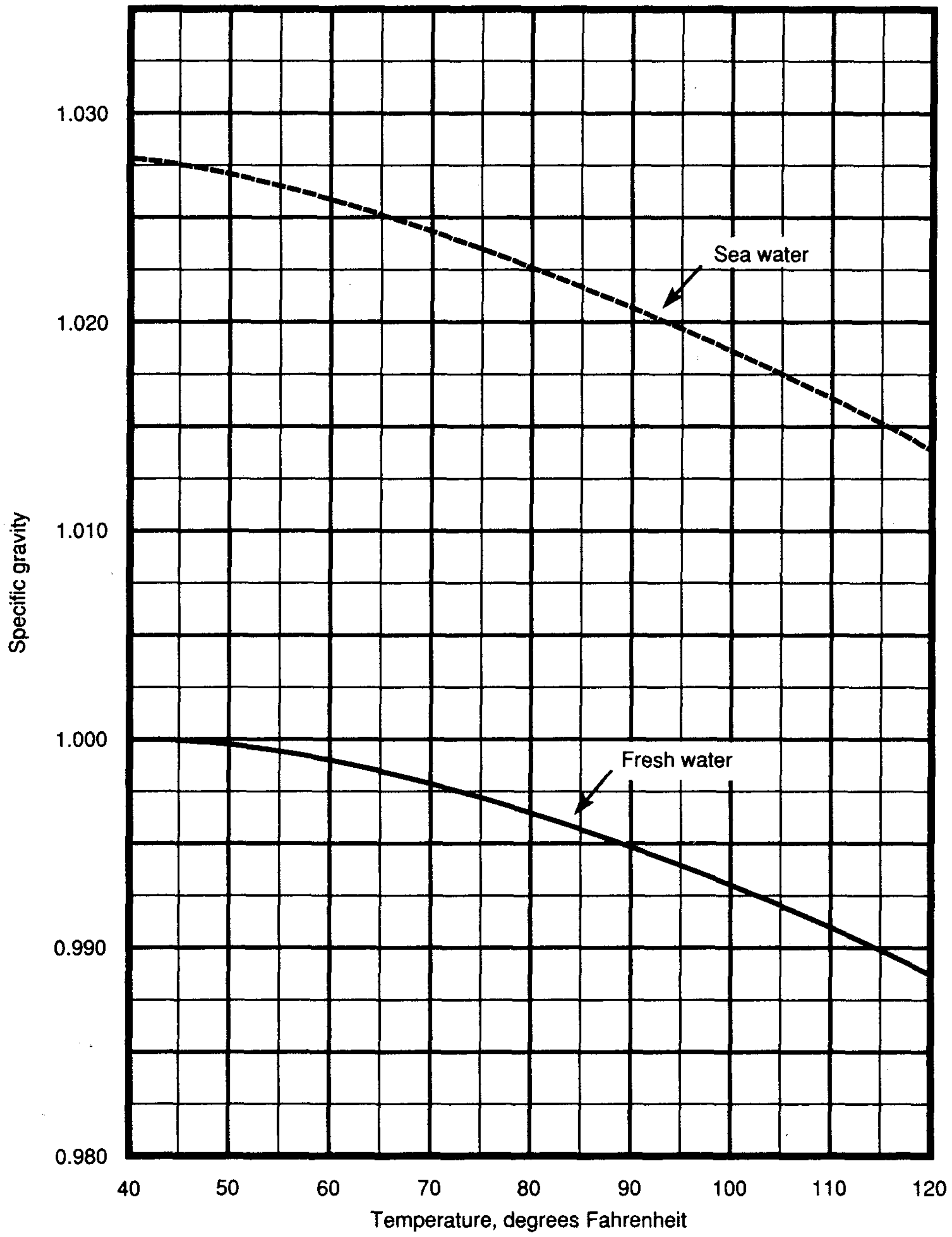


Figure 1—Specific Gravity of Clear Water (Fresh and Sea) for Temperatures Between 40°F and 120°F

arator is beneficial. In the event that such equalization cannot be provided, the separator must handle the design storm flow of direct runoff from the drainage area. The size of the storm flow load on a separator can be estimated based on frequency, intensity, and duration of rainfall. Data on these factors for various localities can be obtained from state and federal agencies. The amount of runoff is a function of rainfall intensity, soil porosity, the size of the drainage area, and the percentage of the area that is paved. If practical, surface runoff that never contacts oil should be excluded from the process wastewater separator system.

When flow exceeds the design capacity of the separator, the separator continues to function, but it does so with reduced efficiency. The frequency and duration of hydraulic overloads can be reduced by providing additional separator capacity. Alternatives are to divert flow that exceeds the design flow allowance to an impounding basin for temporary storage or to separate extraneous flows from the system (for

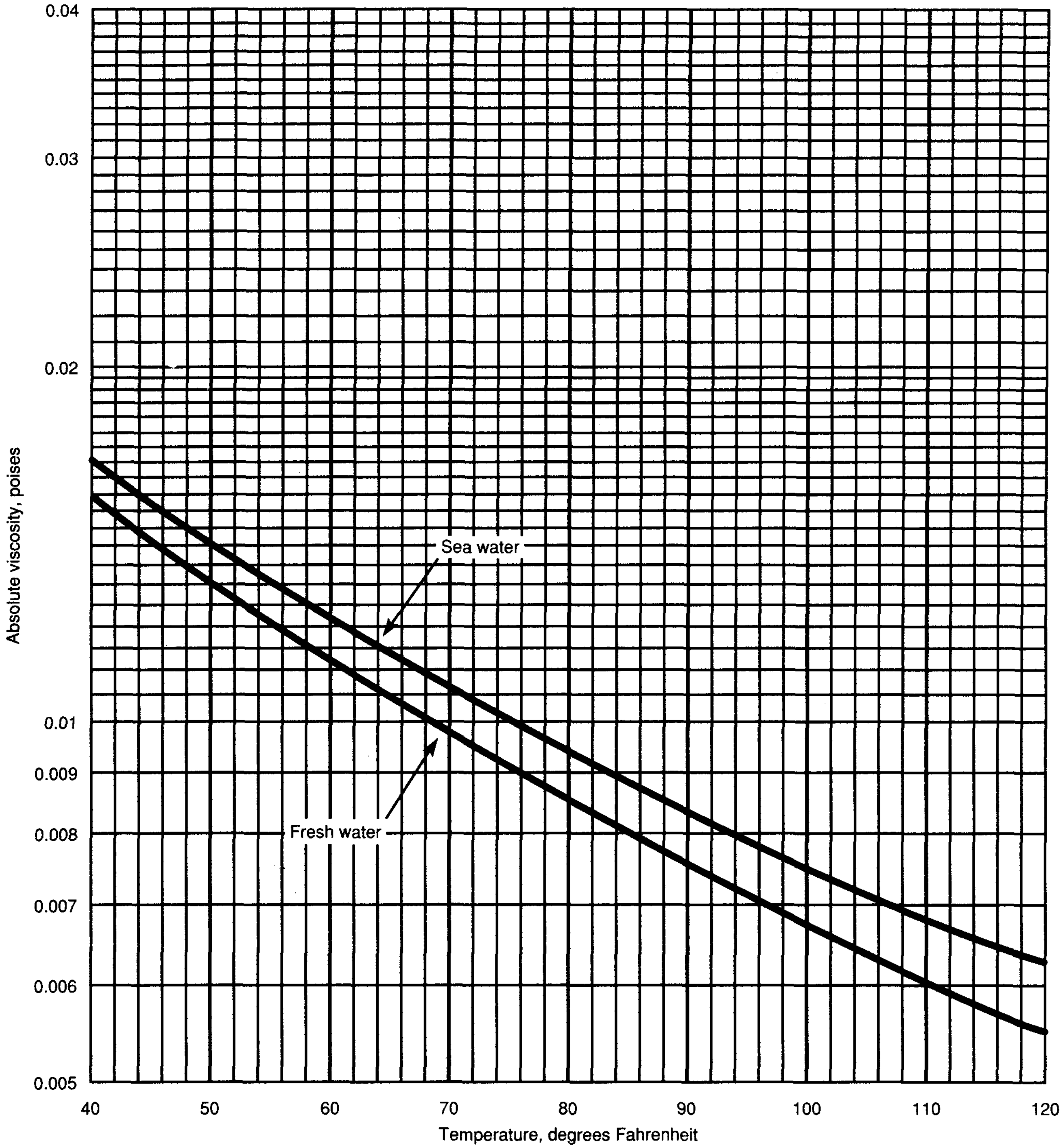


Figure 2—Absolute Viscosity of Clear Water (Fresh and Sea) for Temperatures Between 40°F and 120°F

example, uncontaminated runoff, utility blowdowns, and non-oily process wastewater) for separate handling or tie-in to the wastewater treatment system downstream of the oil–water separator. In certain cases, diversion of low-oil, high-pH waste streams from the separator can enhance its performance.

2.1.4 STEP-BY-STEP DESIGN CALCULATIONS

2.1.4.1 General

As discussed above, the following parameters are required for the design of an oil–water separator:

a. Design flow (Q_m), the maximum wastewater flow. The design flow should include allowance for plant expansion and stormwater runoff, if applicable.
b. Wastewater temperature. Lower temperatures are used for conservative design.
c. Wastewater specific gravity (S_w).
d. Wastewater absolute (dynamic) viscosity (μ).
e. Wastewater oil-fraction specific gravity (S_o). Higher values are used for conservative design.
f. Globule size to be removed. The nominal size is 0.015 centimeter, although other values can be used in conjunction with Equation 1 if indicated by specific data.

The design of conventional separators is subject to the following constraints:

a. Horizontal velocity (v_H) through the separator should be less than or equal to 3 feet per minute or equal to 15 times the rise rate of the oil globules (V_t), whichever is smaller.
b. Separator water depth (d) should not be less than 3 feet, to minimize turbulence caused by oil/sludge flight scrapers and high flows. Additional depth may be necessary for installations equipped with flight scrapers. It is usually not common practice to exceed a water depth of 8 feet.
c. The ratio of separator depth to separator width typically ranges from 0.3 to 0.5 in refinery service.
d. Separator width is typically between 6 and 20 feet and conforms to standard dimensions for flight scraper shaft lengths specified for sludge removal.
e. By providing a minimum of two separator channels, one channel is available for use when it becomes necessary to remove the other from service for repair or cleaning.

The following design suggestions are also made:

a. The amount of freeboard specified should be based on consideration of the type of cover to be installed and the maximum hydraulic surge used for design.
b. A length-to-width ratio (L/B) of at least 5 is suggested to provide more uniform flow distribution and to minimize the effects of inlet and outlet turbulence on the main separator channel.
c. When the target diameter of the oil globules to be removed is known to be other than 0.015 centimeter, Equation 1 should be used to compute oil-globule rise rates. Equation 2 assumes an oil-globule size of 0.015 centimeter and represents a typical design approach.

Figure 3 shows an oil–water separator and depicts the design variables listed above. Repeating Equations 1 and 2,

$$V_t = (g/18\mu)(\rho_w - \rho_o)D^2 \qquad (1)$$

$$V_t = 0.0241\frac{S_w - S_o}{\mu} \qquad (2)$$

Where:

V_t = vertical velocity, or rise rate, of the design oil globule, in centimeters per second.
g = acceleration due to gravity
= 981 centimeters per second squared.
μ = absolute viscosity of wastewater at the design temperature, in poise.
ρ_w = density of water at the design temperature, in grams per cubic centimeter.
ρ_o = density of oil at the design temperature, in grams per cubic centimeter.
D = diameter of the oil globule to be removed, in centimeters.
S_w = specific gravity of the wastewater at the design temperature (dimensionless).
S_o = specific gravity of the oil present in the wastewater (dimensionless, not degrees API).

After an oil-globule rise rate (V_t) has been obtained from Equation 1 or 2, the remaining design calculations may be carried out as described in 2.1.4.2 through 2.1.4.7.

2.1.4.2 Horizontal Velocity (v_H)

The design mean horizontal velocity is defined by the smaller of the values for v_H, in feet per minute, obtained from the following two constraints:

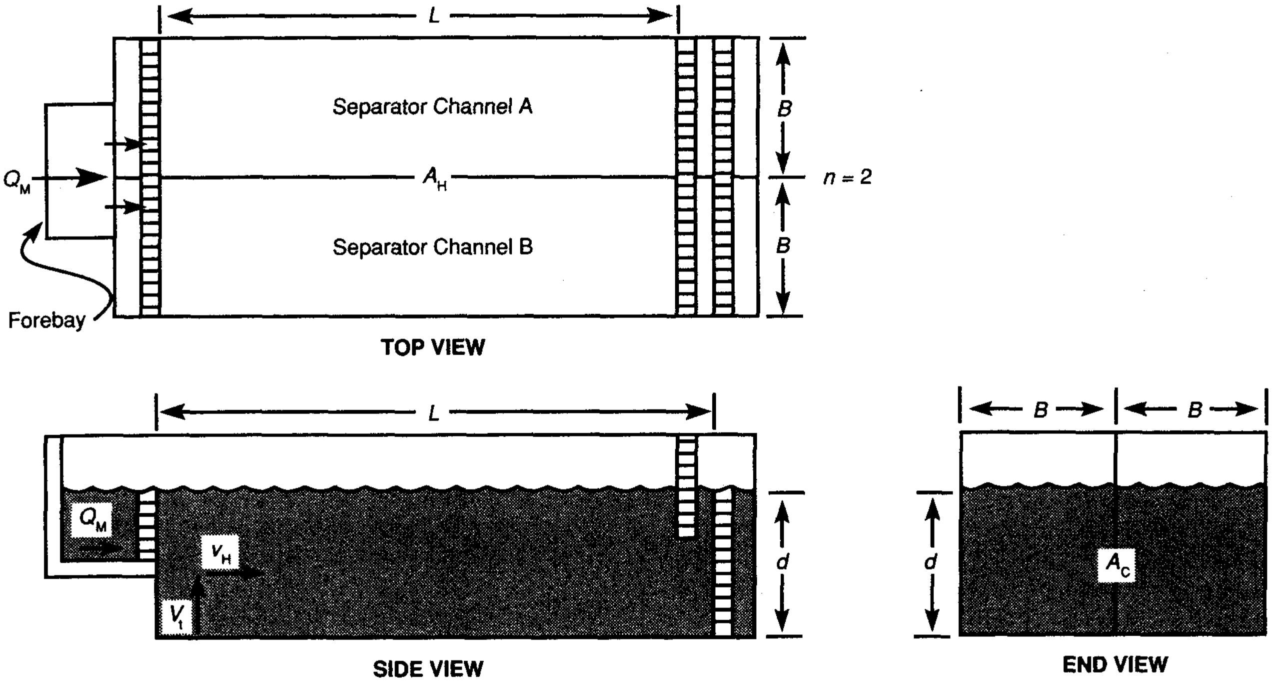
$$v_H = 15V_t \leq 3 \qquad (3)$$

These constraints have been established based on operating experience with oil–water separators. Although some separators may be able to operate at higher velocities, 3 feet per minute has been selected as a recommended upper limit for conventional refinery oil–water separators. Most refinery process-water separators operate at horizontal velocities much less than 3 feet per minute at average flow. All separators surveyed had average horizontal velocities of less than 2 feet per minute, and more than half had average velocities less than 1 foot per minute, based on typical or average flow rates (see Appendix C). Maximum flow rates were not reported in the survey; however, design flow rates were typically 1.5–3 times the typical average flow rates.

2.1.4.3 Minimum Vertical Cross-Sectional Area (A_c) (See Figure 3)

Using the design flow to the separator (Q_m) and the selected value for horizontal velocity (v_H), the minimum total cross-sectional area of the separator (A_c) can be determined from the following equation:

$$A_c = Q_m / v_H \qquad (4)$$



A_c = total cross-sectional area.
A_H = total surface area of separator.
B = width of channel.
d = depth of water.
L = length of channel.
n = total number of separator chambers.
Q_m = influent flow.
v_H = horizontal velocity.
V_t = rise rate of oil globules.

Figure 3—Design Variables for Oil–Water Separators

Where:

A_c = minimum vertical cross-sectional area, in square feet.
Q_m = design flow to the separator, in cubic feet per minute.
v_H = horizontal velocity, in feet per minute.

2.1.4.4 Number of Separator Channels Required (*n*)

In general, the most economical installation is one that minimizes the number of channels required. However, a minimum of two channels is recommended to allow for separator maintenance without bypassing the entire separator. To minimize the number of channels, the cross-sectional area should be maximized in conformance with the design constraints set above. Typically, the maximum cross-sectional dimensions recommended for a single channel are 20 feet wide and 8 feet deep (160 square feet). On this basis, the number of channels (n) required is calculated as follows:

$$n = A_c / 160 \qquad (5)$$

Where:

A_c = minimum vertical cross-sectional area, in square feet.

Fractional numbers of channels are rounded up to the next whole number, based on engineering judgment.

2.1.4.4 Channel Width and Depth

Given the total cross-sectional area of the channels (A_c) and the number of channels desired (n), the width and depth of each channel can be determined. A channel width (B) of between 6 and 20 feet should be substituted into the following equation, solving for depth (d):

$$d = A_c / Bn \qquad (6)$$

Where:

d = depth of channel, in feet.
A_c = minimum vertical cross-sectional area, in square feet.
B = width of channel, in feet.
n = number of channels (dimensionless).

The channel depth obtained should conform to the accepted ranges for depth (3–8 feet) and for the depth-to-width ratio (0.3–0.5). If the depth obtained fails to meet either of these criteria, different separator widths should be tried until a depth that meets these criteria is obtained.

2.1.4.5 Separator Length

Once the separator depth and width have been determined, the final dimension, the channel length (L), is found using the following equation:

$$L = F(v_H / V_t)d \tag{7}$$

Where:

L = length of channel, in feet.
F = turbulence and short-circuiting factor (dimensionless).
v_H = horizontal velocity, in feet per minute.
V_t = vertical velocity of the design oil globule, in feet per minute.
d = depth of channel, in feet.

If necessary, the separator's length should be adjusted to be at least five times its width, to minimize the disturbing effects of the inlet and outlet zones.

Equation 7 is derived from several basic separator relations:

a. The equation for horizontal velocity ($v_H = A_c/Q_m$), where A_c is the minimum total cross-sectional area of the separator.
b. The equation for surface-loading rate ($V_t = Q_m/A_H$), where A_H is the minimum total surface area of the separator.
c. Two geometrical relations for separator surface and cross-section area ($A_H = LBn$ and $A_c = dBn$), where n is the number of separator channels.

A derivation of this equation is given in Appendix A.

The turbulence and short-circuiting factor (F) is a composite of an experimentally determined short-circuiting factor of 1.21 and a turbulence factor whose value depends on the ratio of mean horizontal velocity (v_H) to the rise rate of the oil globules (V_t). A graph of F versus the ratio v_H/V_t is given in Figure 4; the data used to generate the graph are also given.

2.1.4.6 Minimum Horizontal Area

In an ideal separator—one in which there is no short-circuiting, turbulence, or eddies—the removal of a given suspension is a function of the *overflow rate,* that is, the flow rate divided by the surface area. The overflow rate has the dimensions of velocity. In an ideal separator, any oil globule whose rise rate is greater than or equal to the overflow rate will be removed. This means that any particle whose rise rate is greater than or equal to the water depth divided by the retention time will reach the surface, even if it starts from the bottom of the chamber. When the rise rate is equal to the overflow rate, this relationship is expressed as follows:

$$V_t = \frac{d_i}{T_i} = \frac{d_i}{\frac{L_i B_i d_i}{Q_m}} = \frac{Q_m}{L_i B_i} = v_o \tag{8}$$

Where:

d_i = depth of wastewater in an ideal separator, in feet.
T_i = retention time in an ideal separator, in minutes.
L_i = length of an ideal separator, in feet.
B_i = width of an ideal separator, in feet.
v_o = overflow rate, in feet per minute.

Equation 8 establishes that the surface area required for an ideal separator is equal to the flow of wastewater divided by the rise rate of the oil globules, regardless of any given or assigned depth.

By taking into account the design factor (F), the minimum horizontal area (A_H), is obtained as follows:

$$A_H = F\left(\frac{Q_m}{V_t}\right) \tag{9}$$

Where:

F = turbulence and short-circuiting factor (dimensionless).
Q_m = wastewater flow, in cubic feet per minute.

2.1.5 DESIGN EXAMPLE

2.1.5.1 Wastewater Characteristics

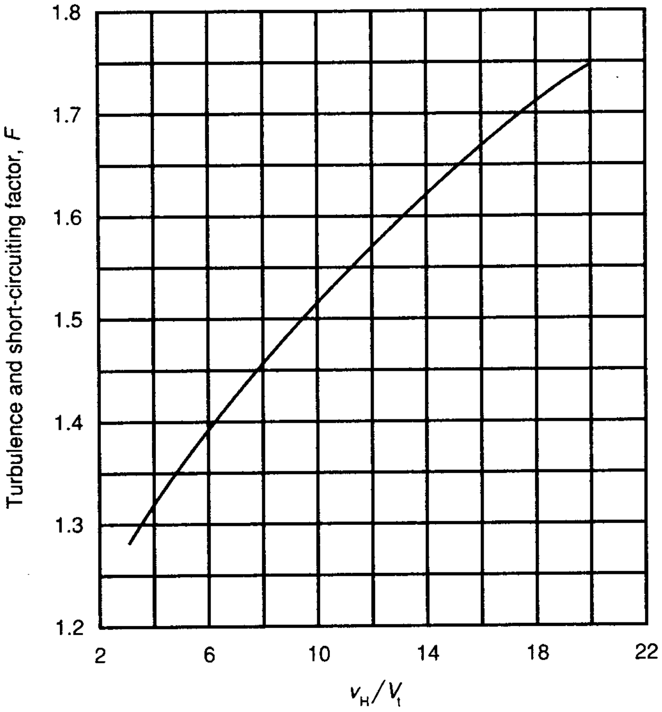
In this example, the wastewater has the following characteristics:

a. A design flow rate (Q_m) of 4490 gallons per minute.
b. A minimum temperature of 105°F.
c. A specific gravity (S_w) of 0.992.
d. An absolute (dynamic) viscosity (μ) of 0.0065 poise.
e. A maximum oil specific gravity (S_o) of 0.92.

2.1.5.2 Design Calculations

2.1.5.2.1 The rise rate for the oil globules is calculated using Equation 2. For a globule with a diameter (D) of 0.015 centimeter,

$$\begin{aligned} V_t &= 0.0241\frac{S_w - S_o}{\mu} \\ &= 0.0241\frac{0.992 - 0.92}{0.0065} \\ &= 0.267 \end{aligned}$$



v_H/V_t	Turbulence Factor (F_t)	$F = 1.2(F_t)$
20	1.45	1.74
15	1.37	1.64
10	1.27	1.52
6	1.14	1.37
3	1.07	1.28

Figure 4—Recommended Values of F for Various Values of v_H/V_t

2.1.5.2.2 The maximum allowable mean horizontal velocity is calculated using Equation 3:

$$\begin{aligned} v_H &= 15V_t \leq 3 \\ &= 15(0.267) = 4 \\ 4 &> 3 \end{aligned}$$

A velocity of 3 feet per minute is used because this is the maximum recommended mean horizontal velocity.

2.1.5.2.3 The minimum vertical cross-sectional area is calculated using Equation 4:

$$\begin{aligned} A_c &= Q_m / v_H \\ Q_m &= 4490/7.48 = 600 \\ A_c &= 600/3 = 200 \end{aligned}$$

2.1.5.2.4 The number of separator channels required is calculated using Equation 5:

$$\begin{aligned} n &= A_c/160 \\ &= 200/160 \\ &= 125 \\ \therefore n &= 2 \end{aligned}$$

Since n must be greater than or equal to 2, this value is acceptable.

2.1.5.2.5 The width and depth of the channels are calculated using Equation 6:

$$d = A_c / Bn$$

Assuming a channel width (B) of 20 feet,

$$d = \frac{200}{(20)(2 \text{ channels})} = 5$$

The value of 5 obtained for d meets the requirement that d be greater than or equal to 3 but less than or equal to 8. However, with $d = 5$, $d/B = 0.25$, which fails to meet the requirement that d/B be greater than or equal to 0.3 but less than or equal to 0.5. Therefore, a smaller value for B must be tried. Assuming a channel width (B) of 18 feet,

$$d = \frac{200}{(18)(2 \text{ channels})} \approx 6$$

The value of 6 obtained for d meets the requirement that d be greater than or equal to 3 but less than or equal to 8. In addition, with $d = 6$, $d/B = 0.3$, which meets the requirement that

d/B be greater than or equal to 0.3 but less than or equal to 0.5. Furthermore, B meets the requirement that it be greater than or equal to 6 but less than or equal to 20. Therefore, a channel width of 18 feet and a channel depth of 6 feet are acceptable dimensions.

2.1.5.2.6 The length of the separator is calculated using Equation 7:

$$L = F(v_H / V_t)d$$

From 2.1.5.2.1 and 2.1.5.2.2, $v_H/V_t = 3/0.267 = 11.23$. Therefore, from Figure 4, $F = 1.55$.

$$L = (1.55)(11.23)(6) \approx 105$$

A check should be performed to determine that L/B is greater than or equal to 5. In this case, L/B is equal to 5.8, so the check is satisfied.

2.1.5.2.7 The separator configuration resulting from this example consists of two channels, each 105 feet long and 18 feet wide, with a water depth of 6 feet plus desired freeboard. The series of calculations above illustrates the fundamental separator chamber dimensions needed for detailed unit design. The construction details given in 2.2 provide information on oil- and sludge-removal equipment and other factors pertinent to the implementation of separator design.

2.2 Construction Details

2.2.1 GENERAL

A conventional oil–water separator installation (see Figure 5) consists of two basic sections—the inlet section and the oil–water separator channels. The components of these sections are discussed in 2.2.2 through 2.2.4, and information on the types of appurtenances currently used is provided.

2.2.2 INLET SECTION

2.2.2.1 General

The inlet area serves to distribute flow to the separator channels. Some separation of oil from the wastewater occurs here in addition to removal of some grit and floating debris. If the separator is to receive highly variable flows, such as those from uncontrolled stormwater runoff, the overall design may need to incorporate criteria for flow equalization.

The main components of a typical inlet section are illustrated in Figure 5. These may include a preseparator flume, a trash rack or automatic bar screen, an oil skimmer, and a forebay. The gateways for channel shutoff are the division between the inlet section and the separator channels. If total separator system bypass is desired, additional gates should be installed at the head of the inlet section.

2.2.2.2 Preseparator Flume

The preseparator flume is located between the end of the inlet sewer and the separator forebay and serves to reduce flow velocity and separate light oil. Velocity reduction is essential for even distribution of flow to the separator channels. Grit deposition and oil separation will occur as a result of the velocity reduction. Velocity reduction with minimum turbulence is accomplished by a transition section located between the inlet sewer and the preseparator section. For good hydraulics, the sides of the transition section are flared laterally and the floor is sloped from the sewer invert to the separator-floor elevation.

The effluent end of the preseparator section usually contains three pieces of equipment: a bar screen or trash rack, an oil skimmer, and an oil-retention baffle, in that order. To minimize evaporative losses, the preseparator flume and transition section may be required to be covered by government regulations.

Note: Refer to "Standards of Performance for VOC Emissions from Petroleum Refinery Wastewater Systems" (40 *Code of Federal Regulations* Part 60, Subpart QQQ), which addresses air emissions from oil–water separators.

Floating oil that has been trapped in this section of the flume should be skimmed and removed at periodic intervals.

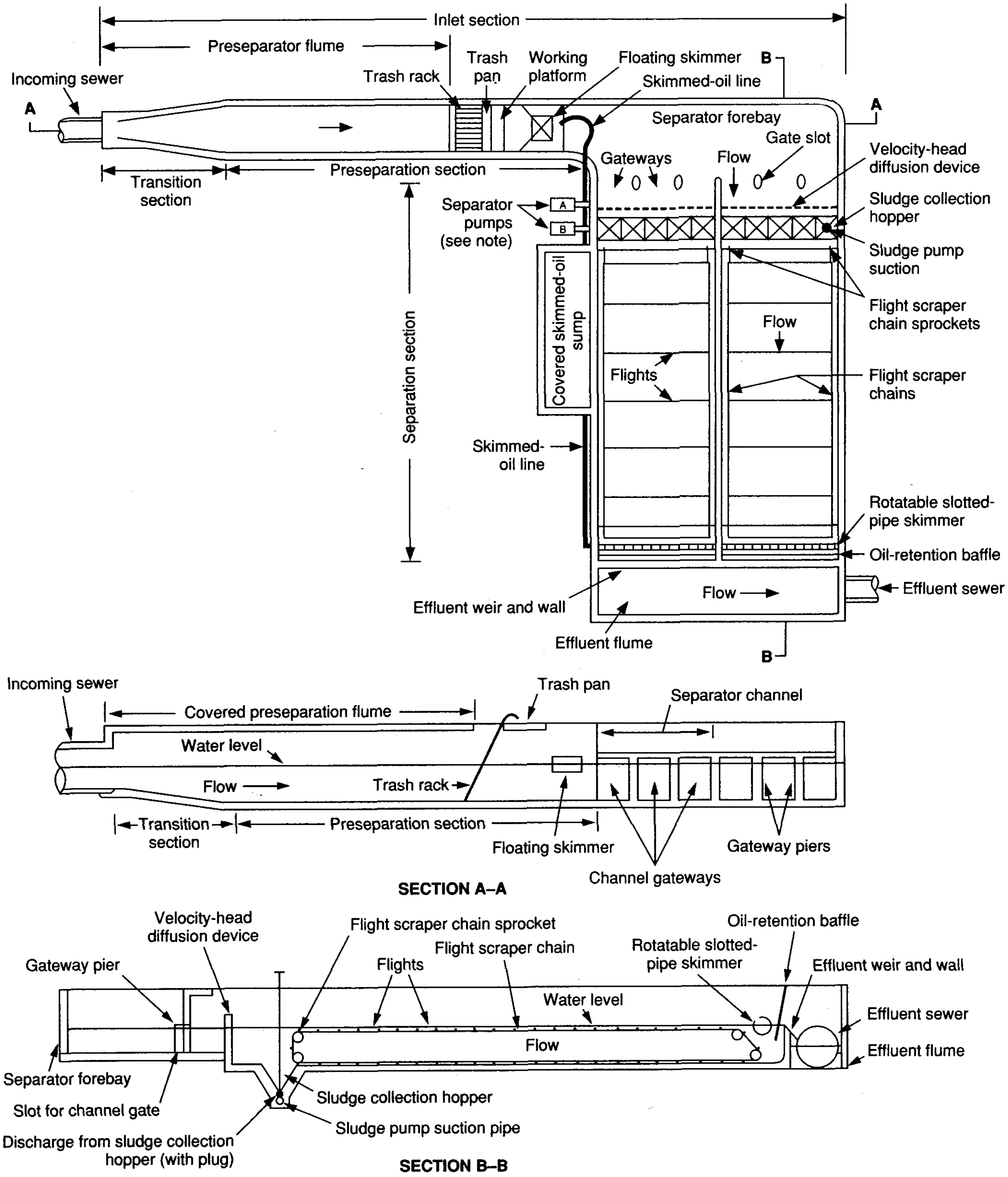
Velocities in the preseparator section on the order of 10–20 feet per minute, with a 1–2-minute detention time, are considered satisfactory. Experience has shown that most of the oil flowing to a separator can be recovered in the preseparator flume or preseparation section. If needed, means should be provided for removal of settleable solids deposited in this section. These means can include grit rakes or provision of multiple channels in the preseparator flume to allow one channel to be taken out of service for cleaning without having to bypass the entire oil–water separator.

2.2.2.3 Trash Rack

Trash racks or bar screens can be placed upstream of the separator to remove sticks, rags, stones, and other debris that would interfere with the operation of downstream equipment. The trash rack consists of a series of inclined bars spaced on 1–2-inch centers, at an angle of 45–75 degrees from the horizontal, depending on the depth of the flume. A perforated pan draining into the flume is provided to receive the debris removed from the bars. Both manually cleaned devices and mechanically cleaned trash racks are available.

2.2.2.4 Oil Skimmer and Retention Baffle

An oil skimmer is generally installed downstream of the trash rack for removal of oil from the inlet section. Rotatable slotted-pipe skimmers are normally preferred for this location. A floating skimmer can be employed where the flow level is expected to vary significantly.



Note: Separator pumps are allocated for specific service as follows but are manifolded to permit sparing and to provide flexibility of operations. Pump A is used to transfer of the oil–water mixture from the skimmed-oil sump to the water-removal vessel. Pump B is used to transfer of sludge from the separator to the sludge-handling facilities.

Figure 5—Conventional Oil–Water Separator (Uncovered)

Skimmers may be manually operated at suitable intervals or automated to skim on a cyclic basis.

When an oil-retention baffle is provided, it should be located not more than 12 inches downstream of the oil skimmer. The baffle's submergence should not exceed 18 inches.

2.2.2.5 Separator Forebay

The preseparator flume discharges into the separator forebay, which distributes the influent to the separator channels. If an upstream grit collector is lacking, sludge is likely to be deposited in the forebay. In the absence of an upstream grit collector, means should be provided for removing or transferring the sludge to the separator for subsequent removal, particularly if a reaction-jet diffusion device is used. Water jets can be used to flush solids from the forebay into the separator zone. This practice can affect the quality of the effluent unless the separator channel is blocked off. Alternatively, the reaction-jet diffusion device can be put at the floor level of the forebay to allow solids to be scoured out of the forebay to the separator channels for collection. An oil skimmer may also be needed in the forebay, depending on whether or not oil is trapped by the flow distribution devices.

2.2.3 SEPARATION SECTION

2.2.3.1 General

The separation channel is a simple flow-through basin that presents no obstruction to the flow so that turbulence is minimized. Separators with long channels are sometimes subdivided into primary and secondary bays to reduce the travel of the sludge scrapers and oil skimmers. The separation channel includes the following appurtenances: gateways, velocity-head diffusion devices (vertical-slot baffles or reaction-jet inlets), oil- and sludge-moving devices, oil skimmers and retention baffles, and oil- and sludge-collection equipment.

2.2.3.2 Gateways

The influent flows from the forebay into the separator channels through shutoff gateways that are made as wide as is practicable. Permanently installed, tight shutoff gates may be provided, but steel sheets or wooden boards sized so that they drop into place when required may also be satisfactory if they can stop flow into a channel. To promote long life and avoid costly replacement, the gateways should be of suitable corrosion- and erosion-resistant materials.

2.2.3.3 Velocity–Head Diffusion Devices

2.2.3.3.1 General

Immediately downstream of the inlet gateways are velocity-head diffusion devices, such as reaction jets or vertical-slot baffles. The functions of these devices are to reduce flow turbulence and to distribute the flow equally across the channel's cross-sectional area.

2.2.3.3.2 Reaction–Jet Inlet

A reaction jet is an alternative diffusion device that may be used instead of a vertical-slot baffle to introduce the influent into the main separating channels and distribute it over the cross-sectional flow area. A hydraulic study of separator inlets sponsored by API at the University of Wisconsin [5] found that a separator provided with reaction-jet inlets yielded an effluent with a lower oil content than that obtained from a separator equipped with vertical baffles.

A reaction jet consists of a tube or orifice and a dished target baffle (see Figure 6). The concave surface of the target baffle faces the orifice or tube. The flow of water from the orifice or tube is reversed by the baffle so that it impinges on the inlet wall of the separator. In this manner, the velocity head is dissipated, and the flow is effectively and uniformly distributed over the channel's cross-sectional area.

Orifices are generally used if the separator forebay is large and flow direction is normal to the inlet wall. Orifices are flush with respect to the inlet wall. Tubes are indicated where approach velocities in directions at an angle to the inlet wall exceed 0.5 feet per second. The tubes project into the separator section from the inlet.

Reaction-jet inlets have been installed based on the following criteria:

a. The baffle's radius of curvature (*R*), in inches, is equal to the tube or orifice diameter (*D*) in inches.

b. A diameter is selected that is sufficient to maintain a design flow velocity of 3 feet per second in the tube or orifice.

c. The baffle diameter ($D + 1$) is 1 inch larger than the tube or orifice diameter.

d. The baffle is located downstream from the tube or orifice at a distance equivalent to 0.25–0.6 of the tube diameter. A proper distance is required to avoid clogging.

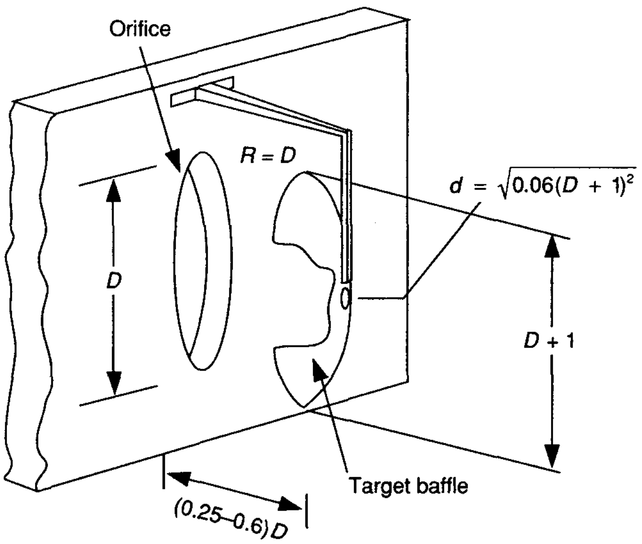
e. A hole may be provided in the center of the baffle to improve distribution. The area of this hole should be 6 percent of the plane area of the baffle (see the formula in Figure 6).

f. To facilitate removal of sludge from the forebay, the centerline of the reaction jet is located at the midpoint of flow depth in the main separator channel and at the bottom of the forebay (that is, the floor of the forebay should be at the midpoint of the separator channel).

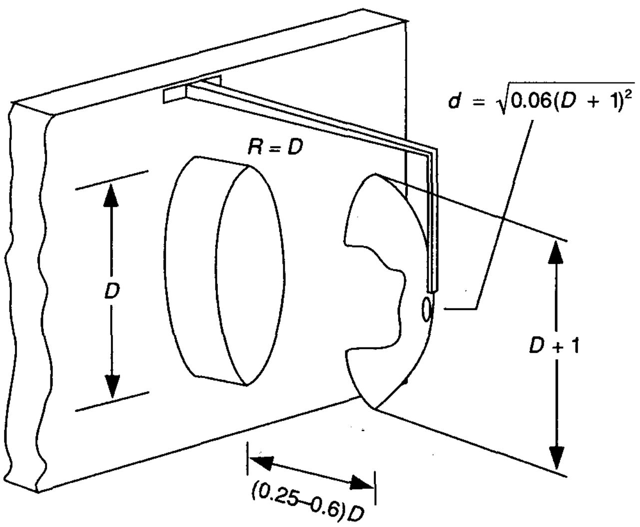
g. Reaction jets are spaced uniformly across the width of the channel. The distance from the channel wall to the first jet is one-half the distance between adjacent jets.

A number of refinery installations of reaction jets examined in an API-sponsored research project [5] are giving satisfactory service.

Reaction jets have a number of advantages:



ORIFICE TYPE



TUBE TYPE

Figure 6—Reaction-Jet Inlets

a. They are not subject to clogging.
b. They provide good distribution over a wide range of flow rates.
c. They are less costly than other devices.

Dimensions and installation details for reaction jets are available from equipment vendors.

2.2.3.3.3 Vertical-Slot Baffle

A vertical-slot baffle (see Figure 7) consists of upright members spaced across the channel inlet so that the open areas between members are at least ½ inch wide and larger than the bar screen openings.

The shape of the members is not critical, although rectangular posts are the most commonly used. Having the upstream opening narrower than the downstream one can facilitate cleaning and dissipate velocity. Pipes have also been used as members. The spacing of members need not be uniform; in general, the closer the spacing the better, as long as clogging does not become a problem. Where high local influent velocity is a problem, baffle members should be more closely spaced. Manual cleaning of the baffle is occasionally necessary.

The baffle members are inserted singly or as a section into the channel sides and floor, flush with the channel bottom and extending above the design water level.

The design of vertical-slot baffle systems is based on the percentage of free space within the areas delineated by the baffle system. This should be equivalent to 3–7 percent of the channel's cross-sectional area. Figure 7 shows a typical baffle arrangement. In this case, a baffle with a trapezoidal cross-section was used to cause a reduction in flow velocity across the baffles.

2.2.3.4 Oil- and Sludge-Moving Devices

Depending on the volume and characteristics of solids and oil, mechanical equipment may be provided to move the substances to the collection point. The purpose of oil- and sludge-moving devices is to convey separated sludge and surface oils to a collection point to permit easy removal of these materials. There are two common types of mechanical oil- and sludge-moving devices: the chain type and the span type.

The four-shaft collector (see Figure 8) consists of two parallel chains moved by motor-driven sprockets. These chains carry flights that extend across the width of the channel. As the surface flights travel downstream, separated oil is moved toward the oil skimmer. On the return trip, the flights move along the channel floor, pushing sludge toward the sludge-collecting hoppers or trough at the influent end. Operation of the unit can be controlled either manually or automatically.

The span or traveling bridge (see Figure 9) is located above the channels, spanning one or more of them. This unit moves on rails located on top of the channel walls. On the downstream trip, the oil-moving flight is submerged to move separated oil. During this trip, the sludge-moving blade is either horizontally positioned or raised out of the channel. At the end of the run, the oil-moving blade is raised out of the water and the sludge-moving blade is properly positioned to move sludge on the return trip upstream. Operation of this unit can be manual or automatic. This design is not common and has not been used on units equipped with covers.

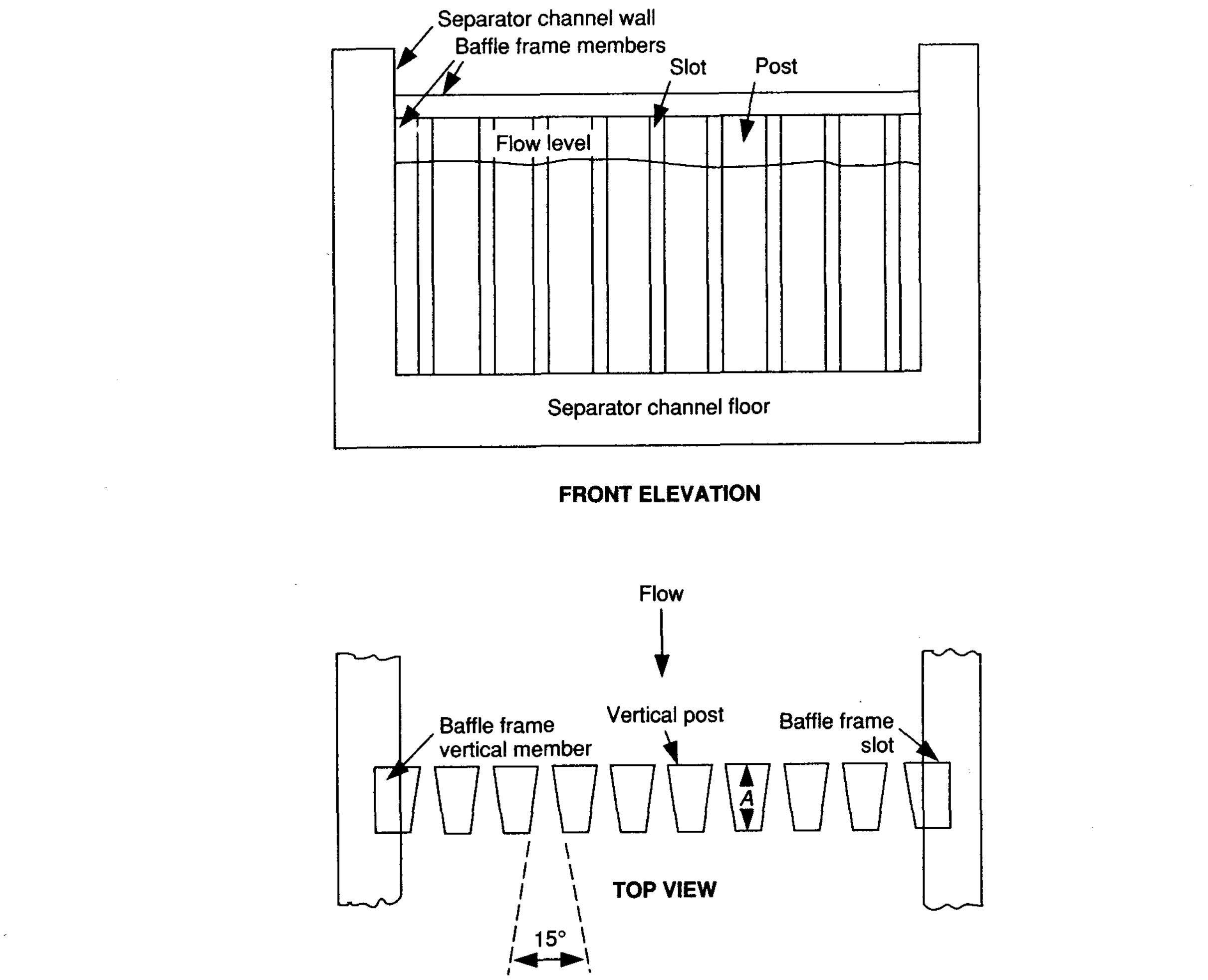


Figure 7—Vertical-Slot Baffle

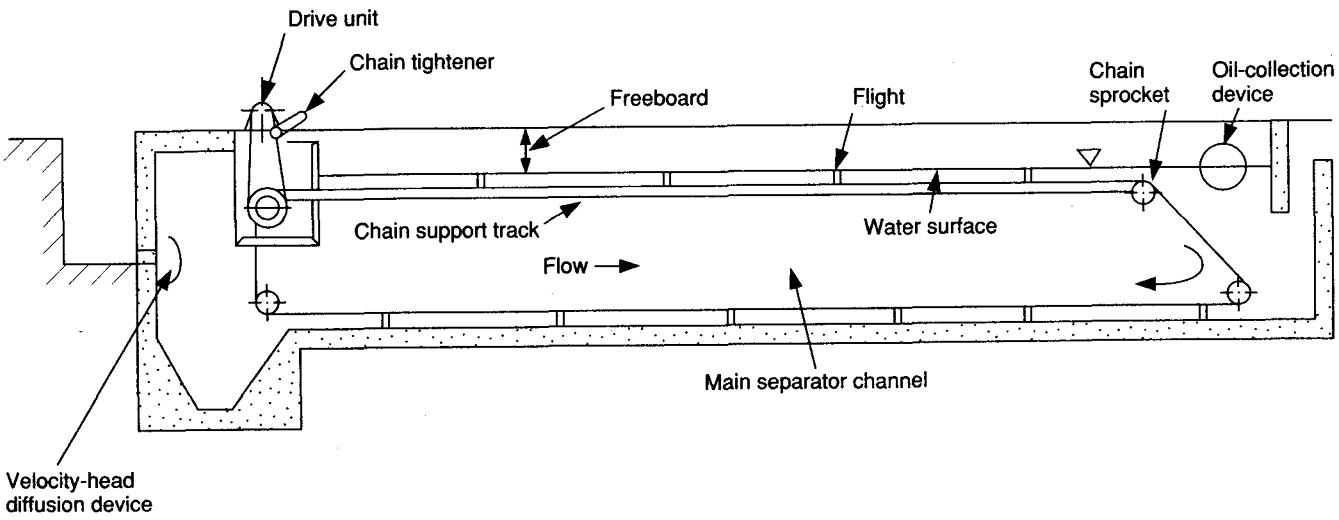


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Figure 8—Four-Shaft Collector-Type Oil- and Sludge-Moving Device

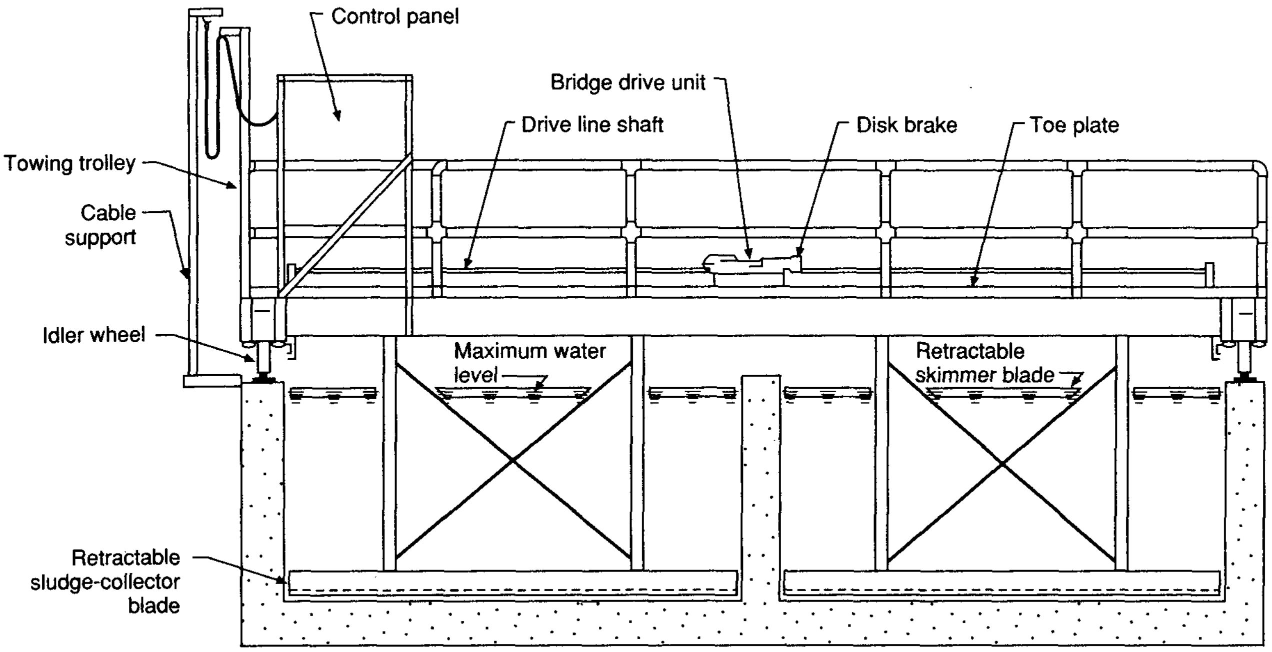

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Figure 9—Traveling-Bridge Oil Skimmer and Sludge Collector

Both types of devices are commercially available from a number of manufacturers. Because information is readily available from vendors, design details are omitted here.

For units equipped with covers, suction sludge-removal equipment is available from several manufacturers of clarifier equipment. Experience with these types of devices in petroleum refineries is limited.

2.2.3.5 Oil-Skimming Devices

An oil-skimming device should be provided at the end of the main channel or separation section. The method selected for removing oil from the oil–water separator and the proper functioning of the system is crucial to the effective operation of the separator.

Several types of oil-skimming devices are in use: the rotatable slotted-pipe skimmer, the rotary-drum skimmer, and the floating skimmer. The most common of these is the slotted-pipe skimmer.

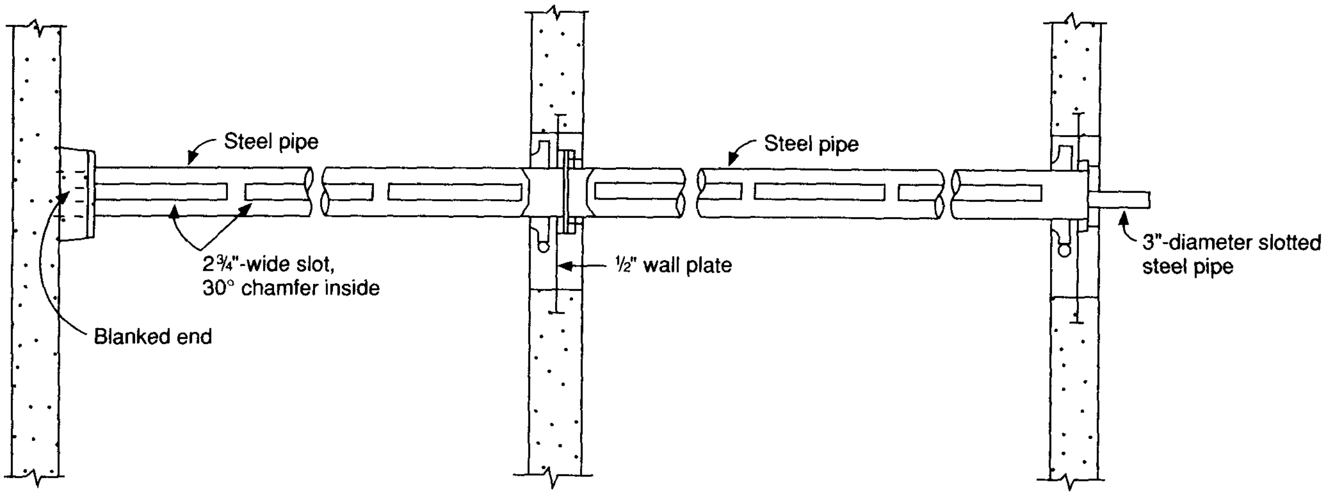
The rotatable slotted-pipe skimmer (see Figure 10) is the oldest and the most common type in general use. Since the device is commercially available, additional information can be obtained from manufacturers. The proper skimming level can be adjusted by rotating the pipe. The skimmer should be capable of being rotated both backward and forward over a range of 180 degrees so that the separated oil that collects between the skimmer and the oil-retention baffle can be recovered. This is a simple device and is usually manually adjusted, but it can have the disadvantage of picking up a relatively large volume of water along with the skimmed oil unless the slot elevation is properly set. It can be made to operate automatically by providing the proper control and actuating equipment. The amount of water included with the skimmed oil depends on the care exercised in submerging the slot and on adjusting it during the skimming operation. When used in a multiple, parallel-chamber separator installation, rotatable slotted-pipe skimmers are connected end to end in a line that drains to a sump located at one side of the installation. The oil skimmed from the channel farthest from the sump must flow to it through each of the succeeding skimming pipes. As a result, each succeeding downstream skimmer pipe should be large enough to allow collected oil from other channels to flow by gravity to the sump.

The rotary-drum skimmer (see Figure 11) is available in both floating- and fixed-level modes. The principle of operation is the same for both types. Skimming is accomplished by a drum that rotates with the flow and picks up a thin film of oil, which is scraped off and drained into a collecting sump. The drum can be made of carbon steel, stainless steel, aluminum, or plastic. The optimal tangential velocity of the drum is on the order of 0.5–1.5 feet per second, with a submergence of 0.5 inch or more. The optimal rotational speed depends on the amount of oil to be removed and its viscosity. Submergence is not critical as long as the drum is in contact with the oil layer. The advantages of this unit are that the recovered oil contains relatively little water and its operation an be made automatic.

Several types of floating skimmers are also available. The horseshoe-type floating skimmer (see Figure 12) consists of a buoyancy chamber, a skimming weir, an oil-collecting pan, and a discharge orifice attached to a hose that conveys skimmings to a sump. The self-adjusting floating skimmer (see Figure 13) is a box within a box, with the inner box serving as a buoyancy chamber. During the skimming operation, liquid must be removed by pumping from the rear of the outer box. When this is done, buoyancy is upset, causing the front of the outer box to tilt forward and submerge the skimming weir. When pumping is stopped, the skimmer returns to its normal inoperative position. Neither of these floating skimmers is frequently used in refinery separator installations. Further information on these skimmers is available from equipment vendors.

2.2.3.6 Recovered–Oil Sump

Recovered skimmed oil flows to a sump from which it is pumped to another vessel for water removal by a variety of chemical or physical processes. The sump's design is based on the estimated volume of oil collected over a given time period and on the desired frequency of transfer-pump operation. Transfer-pump operation should be controlled by high-



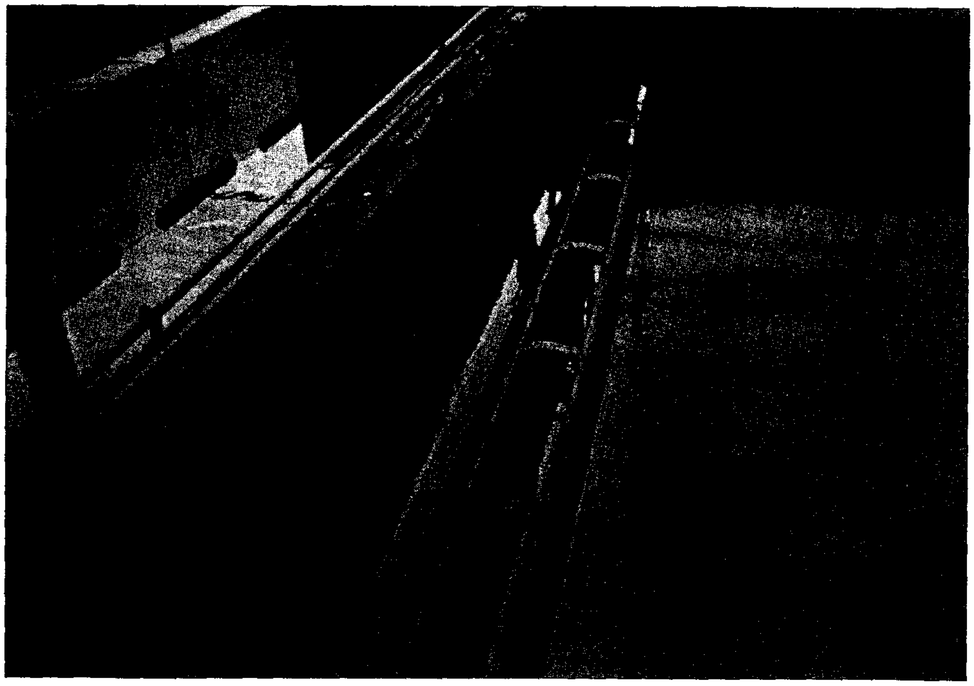


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Figure 10—General Arrangement of Rotatable Slotted-Pipe Skimmer

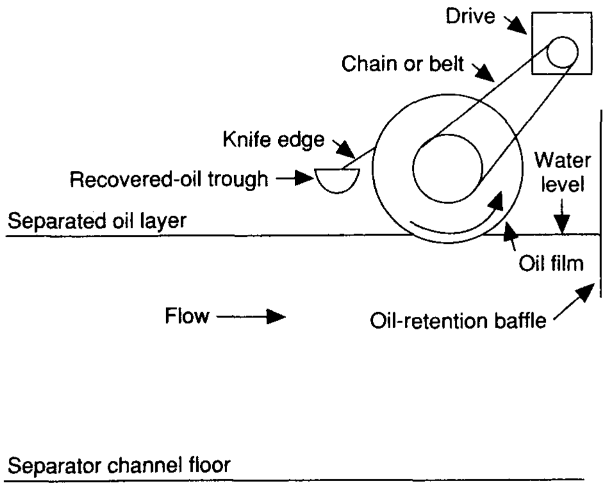


Figure 11—Rotary-Drum Oil Skimmer

and low-level switches. High- and low-level alarms are also suggested to guard against sump overflow and pump cavitation, respectively.

2.2.3.7 Oil-Retention Baffle

An oil-retention baffle should be provided not more than 12 inches downstream of the skimming device. This baffle, usually made of carbon steel or concrete, is installed with a maximum submergence of 55 percent of the water depth. Increased baffle depth could lead to decreased oil and solids separation. The baffle may be installed vertically, or it may be inclined up to 15 degrees from the vertical in the downstream direction (see Figure 5). The baffle should extend to the top of the channel.

2.2.3.8 Sludge Collection and Removal

Sludge can be removed from a separator in several ways, including gravity or augered flow to a pump sump and direct pumping or siphoning from hoppers. In some installations where settleable solids are minimal, sludge can be manually removed when enough sludge has accumulated to require removing the channel from service.

Under the Resource Conservation and Recovery Act (40 *Code of Federal Regulations* Part 261.32), oil–water separator sludge is a listed hazardous waste. Because of its hazardous classification, special handling procedures for hazardous wastes should be followed. For example, oil–water separator sludge should not be mixed with nonhazardous wastes if the mixture will be hazardous. Sludge disposal should be in accordance with applicable regulations governing disposal of hazardous wastes. The sludge will need to be dewatered before landfill disposal, since no free liquids are allowed.

Sludge may be collected in hoppers or V-bottom troughs located on the separator floor. Sludge-collection hoppers at the influent end of the main channel section are inverted pyramids whose sides slope at least 45 degrees to the exit at the apex. There are two principal mechanisms for removing sludge from these hoppers. Each hopper may discharge by gravity into a sludge-withdrawal pipe extending beneath the row of hoppers to a sludge pump. Alternatively, each hopper exit an be fitted with a plug that can be lifted manually, raised by a foot pedal, or elevated by a screw stem. Instead of the underdraw system, sludge may be removed from the hopper by a siphon pipe, using hydrostatic pressure. When this is the case, there may not be an exit in the hopper bottom.

A sludge-collecting V-bottom trough may be used instead of hoppers. The trough is built in the channel across the channel's total width on the downstream side of the vertical-slot baffle or reaction-jet wall. The sides of the trough should have a slope of at least 45 degrees. The bottom should slope toward a collection point at the deep end. Sludge is pumped from the collection point through either an underdrain or a siphon pipe similar to that described for the hoppers. The success of sludge collection in the V-bottom trough depends

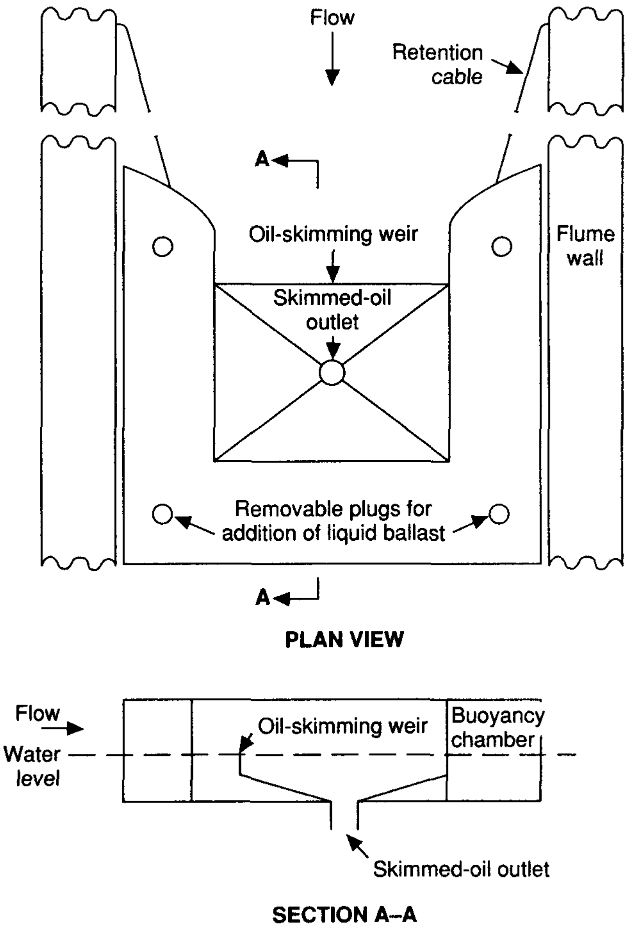


Figure 12—Horseshoe-Type Floating Skimmer

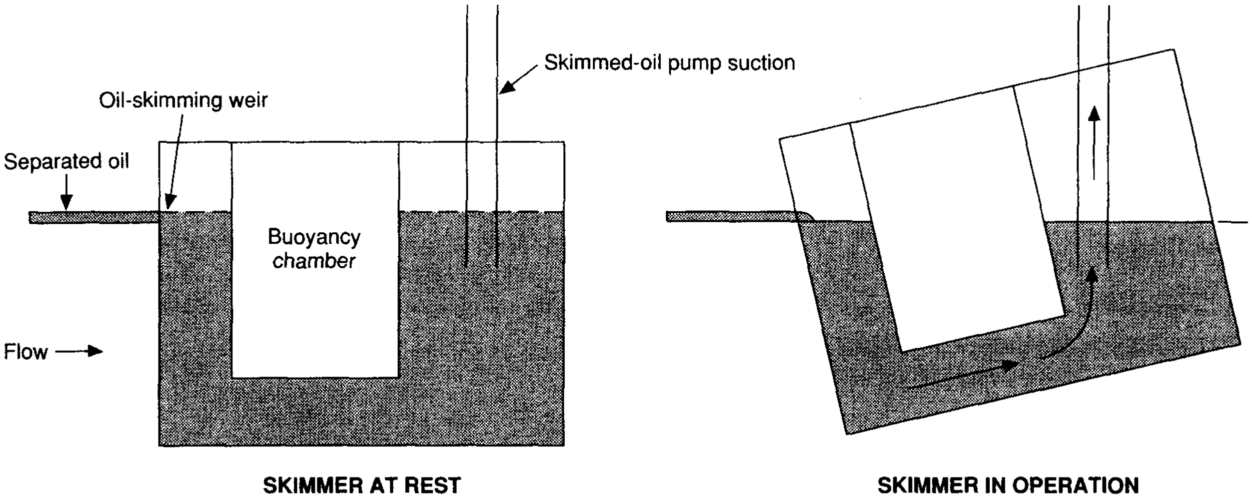


Figure 13—Self-Adjusting Floating Skimmer

on the flow properties of the sludge. Screw conveyors or other cross-collecting devices may also be used to move the sludge toward the collection point for pump-out.

Another alternative to the sludge-removal mechanisms described above is manual sludge removal. With this method, separator chambers are taken out of service on an alternating basis as needed; the chambers are drained, and accumulated sludge and silt are removed either manually or by vacuum truck. For installations with excess separator capacity or where separator effluent oil levels are not critically affected by taking a separator channel out of service, thus increasing the channel surface-loading rate, such a procedure can be an alternative to an in-place mechanical sludge-removal system. It should be noted that many of the conventional separators reported on in the 1985 API Refinery Survey practiced this type of sludge removal.

2.2.3.9 Effluent Weir

The wall of the outfall or effluent weir is located not more than 2 feet downstream of the oil-retention baffle. It extends from the floor of the channel to a height equal to the normal water depth minus the depth of normal flow over the crest (top edge) of the weir. The crest corresponds to the head on the weir.

A sharp-crested or notched steel weir plate is attached to the downstream face of the weir wall along its top. Bolt holes in the plate should be elongated vertically so that the weir plate can be made absolutely level when installed and minor adjustments in elevation can be made.

The effluent flows over the weir into a channel or flume and is conveyed to subsequent wastewater treatment units or to the outfall sewer. Excessive turbulence of the free fall over the weir into the outfall channel may create an oily aerosol. This situation can be minimized by modifying the downstream face of the effluent weir wall to resemble a spillway.

2.2.4 OTHER DESIGN FEATURES

2.2.4.1 General

The design and construction of a new oil–water separator installation or the modernization of an old one presents problems that are peculiar to a refinery's layout and location. In additional, federal and state regulatory developments (for example, New Source Performance Standards) may further influence new construction or modernization. Certain issues common to most refineries are discussed in this subsection.

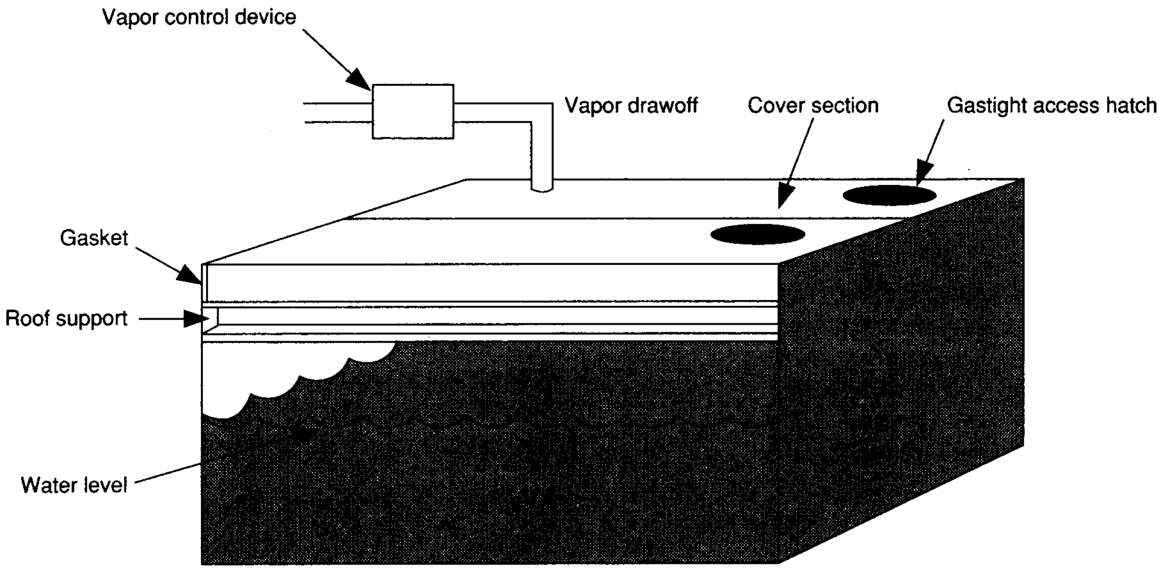
2.2.4.2 Vapor Loss Control

Vapor losses from oil–water separators may be controlled with fixed- or floating-roof covers. Because there is a vapor space under fixed-roof covers, the potential for explosion hazard needs to be considered. In some cases, although not typically in refineries, vapors are collected and are recovered or vented to a vapor control device to further reduce emissions and reduce the explosive hazard. Another option is to provide gas blanketing of the vapor space. Despite the added complexity of vapor recovery and controls for these covers, fixed-roof covers have the benefit of not interfering with mechanical sludge-removal devices. Floating-roof covers rest directly on the oil–water separator's liquid surface and so do not provide the opportunity for significant volumes of vapors to accumulate. In retrofitting separators with conventional skimmer equipment, the liquid level may need to be raised (or the equipment lowered) to accommodate the covers. In some cases, covering the preseparator flume or front end of the separator provides adequate control of vapor losses. Practice varies, and each proposed installation must be evaluated for conformance with applicable federal, state, and local air emission requirements and for safety considerations.

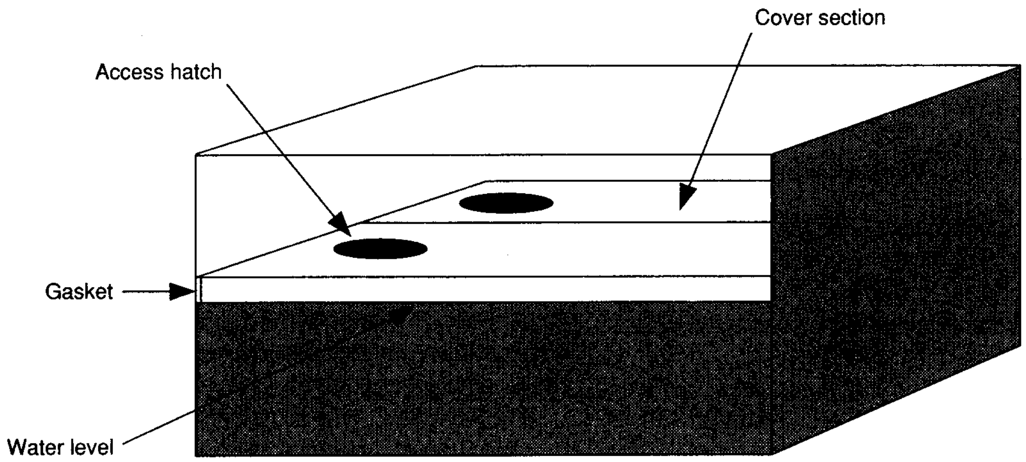
The results of the 1985 API Refinery Survey showed that of 22 covered or partially covered separators, 11 had fixed-roof covers and 9 had floating-roof covers. In some instances covers were restricted to preseparator flumes, forebays, or primary chambers. Carbon steel covers predominated, accounting for 50 percent of covers in use. Fiberglass and fiberglass/urethane/styrofoam composites were used in 7 of the 22 covers. Concrete has also been used for fixed-roof covers. Diagrams of typical fixed- and floating-roof covers are shown in Figure 14.

2.2.4.3 Elevation

A good hydraulic grade in the sewer system is important. Where possible, flow to the separator should be by gravity. To minimize the emulsification of oil and the remixing of separated oil in the wastewater flow, pumping of separator influent should be avoided. In some cases, this has required construction of separators at low elevations and effluent pumping. In some refineries, this situation has been overcome by installing Archimedes'-screw pumps to raise the influent into the separator. Although some emulsification may occur, these devices are believed to have less of an emulsifying effect than do centrifugal pumps, which are commonly used for other wastewater pumping applications.



FIXED–ROOF TYPE



FLOATING–ROOF TYPE

Figure 14—Covers for Oil–Water Separators

2.2.4.4 Unit Separators

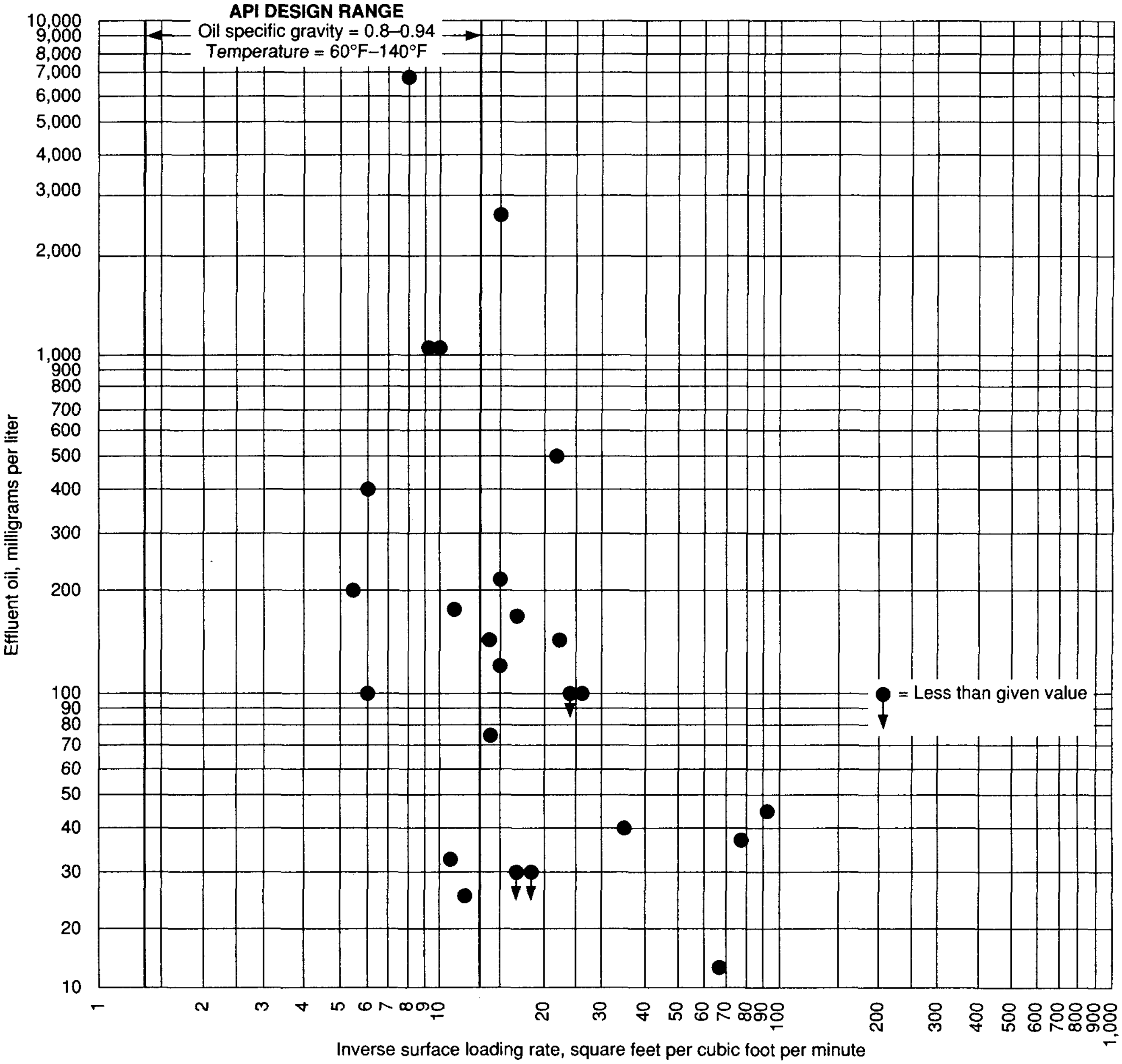
Use of oil–water separators on individual process wastewater streams (for example, desalter wastewater) may be appropriate in some cases. Their use may reduce the load on end-of-pipe treatment units and improve performance if an overload condition exists.

2.2.4.5 Materials of Construction

Reinforced concrete has generally been the construction material of choice for below-grade oil–water separators. Steel separators have been commonly installed above grade. Such factors as corrosion, leakage, structural strength, and buoyancy should be considered in the selection of materials.

2.3 Performance

Based on the 1985 API Refinery Survey of 32 conventional separators, such separators should not be expected to achieve effluent oil levels lower than 100 parts per million. Very few separators that had ratios of surface area to flow within the API design range achieved effluents lower than 100 parts per million (see Figure 15). An examination of



Note: The data in this figure are taken from the 1985 API Refinery Survey.

Figure 15—Performance of Conventional Oil-Water Separators

Figure 15 indicates the wide range of effluent oil levels achieved at similar ratios of surface area to flow.

The relationship between oil specific gravity, droplet size, temperature, and efficiency of oil removal is described in 1.3. The effect of influent oil levels on achievable effluent oil concentrations observed in the survey data for conventional oil–water separators is shown in Figure 16. Because of the high degree of scatter inherent in the data, a strong correlation between influent and effluent oil levels could not be established. Of separators with effluent levels less than 100 parts per million, 8 of 10 had ratios of surface area to flow that were higher than the ratios obtained using the API design procedures. For separators exceeding the API method's surface-loading design range, only half achieved effluent levels less than 100 parts per million. It should therefore be noted that increasing separator surface area significantly may not result in markedly increased oil removal. Most of the separators evaluated were operating considerably below their design flows, with effluent oil levels typically in the range of 50–200 milligrams per liter. The results of the API survey are presented in Appendix D.

The design of oil–water separators to achieve effluent oil levels less than 100 parts per million should take into account the tradeoff between increasing separator size and cost to achieve lower effluent limits and increasing loadings to downstream units by using a less conservatively designed separator.

SECTION 3—IMPROVING THE PERFORMANCE OF EXISTING SEPARATORS

3.1 General Approach

The following are the most common situations in which it becomes necessary to improve the performance of an existing separator:

a. Poor performance resulting from changes in the characteristics of the influent oil or flow.
b. Poor performance resulting from inadequate oil–water separator design.

There are a number of ways of improving separator performance. However, before any approach is taken, the reasons why the separator is not performing adequately should be pinpointed. Before a decision is made to modify the unit, a thorough process troubleshooting effort should be made.

3.2 Process Troubleshooting

3.2.1 DESIGN REVIEW

The first step in process troubleshooting is to examine the design basis for the separator to determine whether the separator is still within suggested API design criteria under its current operating conditions. To do this, it is necessary to obtain the following representative data:

a. Wastewater flow rate (average and peak).
b. Wastewater temperature (preferably for the conditions during which poor performance has been experienced).
c. Specific gravity of the oil entering the wastewater stream. (If more than one source of oil is involved, the densest oil should be selected to permit a conservative analysis of performance.)
d. Channel dimensions (length, width, and depth) and influent oil loading (both free and total).

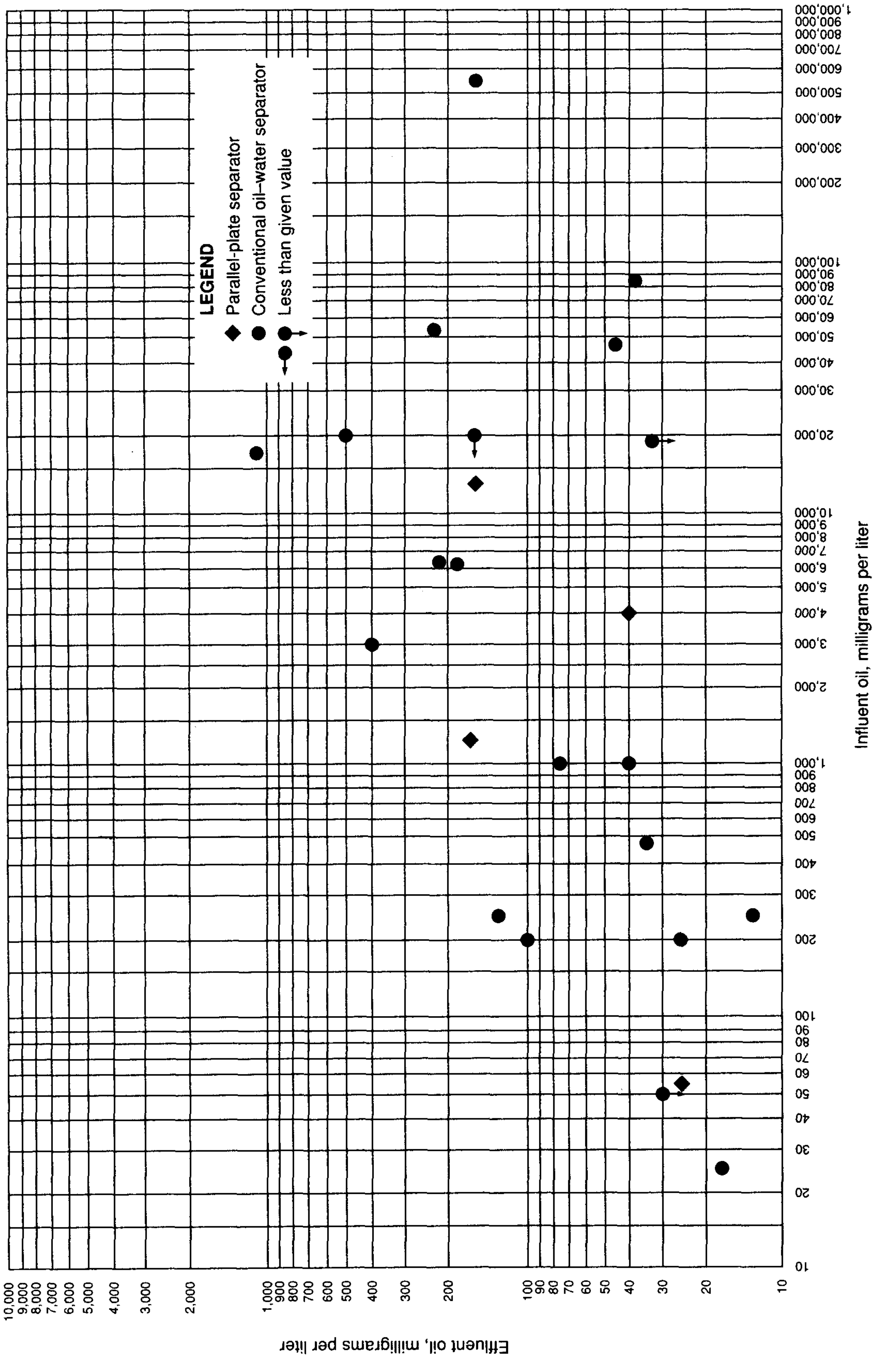
Once these data are available, it is possible to check the separator design using the step-by-step approach presented in 2.1. If the separator is still within the design criteria under current conditions, the analytical methods and data should be reviewed to determine if an explanation is apparent.

3.2.2 EMULSIFIED OIL

In some cases, the presence of emulsified or dissolved oil or other compounds not removable by gravity separation is responsible for poor separator effluent quality. The wastewater entering the separator should be subjected to the determination of susceptibility to oil separation described in 2.1.2.2 and presented in Appendix B. If the oil content of the water phase remaining after the separation period exceeds the design criteria and is of the same order of magnitude as that in the effluent from the actual separator, then the problem is not likely to be with the separator design. Rather, the emulsified or dissolved oil in the wastewater, which is not removed by conventional oil–water separation, is the most likely cause of poor separator effluent quality.

If there are multiple potential sources of emulsified or dissolved oil, then each of these contributing streams should be checked in the manner described above to pinpoint the major sources of these oils. Individual process streams should be investigated to assess their oil load and potential for affecting separator operation. Specific streams to be investigated are desalter brines, caustic streams, sour waters, and delayed-coker cutting water. These streams constitute most of the flow to any refinery wastewater treatment plant. Refineries engaged in the production of lubricating oils may also have problems with streams from furfural extraction and lube-oil blending-tank washdown.

Refinery caustic streams may be a source of dissolved oils (for example, acid oils), and fresh caustic entering the wastewater prior to the separator may raise the pH, making some oils more soluble. The possibility of surfactants, such as might be found in industrial cleaners, entering wastewater



Note: The data in this figure are taken from the 1985 API Refinery Survey.

Figure 16—Correlation Between Influent and Effluent Oil Levels for Existing Oil–Water Separators

streams should also be examined, since such compounds encourage the formation of emulsions.

Free oil can also become emulsified through excessive agitation and turbulence, such as might be encountered in high-velocity piping or transition structures upstream of the separator. Centrifugal pumps have also been known to contribute to the emulsification of free oil.

3.2.3 FLOW SURGES

For best performance, the flow rate through the separator should be as uniform as possible. Large surges in flow to the separator can disrupt its performance, even if they only occur for short periods of time. Unless a continuously recording flowmeter is installed on the inlet to the separator, surges may not be readily apparent. Common sources of flow surges include direct stormwater runoff, on–off pumping of process wastewater or runoff, and periodic washdown of large process areas.

3.3 Dealing with Emulsified Oil

If it has been determined that emulsified oil is the likely cause of the problems with the quality of the separator effluent and all sources have been investigated to prevent the introduction or formation of emulsified oil, then some improvement in effluent quality can be achieved by means of pH control, chemical emulsion breakers, or both. For the best emulsion control, the pH should be maintained between 6 and 7. In most instances, for emulsion breakers to be most effective, they should be added to the wastewater as far upstream of the oil–water separator as is practical, before the emulsified wastewater is greatly diluted by other flow. If the separator influent is pumped via high-shear pumps, it may be advantageous to inject emulsion breakers downstream of the pump discharge. Trial runs at several locations may be necessary to optimize the system.

A number of proprietary emulsion breakers are available through specialty chemical suppliers. Their effectiveness in specific situations is best determined by testing. Bench-scale treatability tests should therefore be performed to determine whether the use of proprietary breakers is warranted and, if so, which ones will perform best. If biological treatment is downstream of the point of chemical addition, it is important that the chemical additive selected not adversely affect the performance of that unit's biomass. Also, if the separator discharges directly to a receiving stream, the amount of the chemical in the discharge should be checked to ensure compliance with applicable discharge limitations.

Because chemical additives are expensive, it is usually best to treat emulsions as close to the source as is possible. The more the emulsified stream is diluted by other wastewaters, the more chemical will need to be added to break the emulsion. The duration and degree of mixing of the emulsified wastewater with an emulsion breaker are also critical to the cost-effectiveness of a chemical addition program.

3.4 Retrofitting Existing Separators With Parallel Plates

A discussion on the theory and application of parallel-plate separators is provided in Section 4. Parallel plates are available in modules that can usually be retrofitted into a conventional separator without major structural modifications.

Without mechanical sludge-removal equipment, parallel-plate retrofitting may not be practical, since manual sludge removal can require raising the plate pack from the separator at regular intervals.

In theory, parallel-plate modules can improve performance in two ways:

a. They provide an increase in the separator's effective horizontal surface area without requiring an increase in the size of the separator basin.
b. They create more uniform, less turbulent flow characteristics, thus providing more favorable conditions for separation of free oil.

When properly done, the retrofitting of parallel-plate modules into an existing separator can either increase the capacity of the separator to accommodate higher flow rates or decrease the effluent oil under the same flow conditions. Parallel-plate separators are theoretically capable of removing smaller globules of free oil than are conventional separators, but they still cannot remove emulsified or dissolved oils.

Although the design of parallel-plate equipment follows the same basic principles used in the design of conventional separators, a wide variety of inlet, outlet, oil- and sludge-removal, and plate-pack configurations are available. Intraplate spacing and plate angle are critical to the proper performance of the plate pack.

Since parallel-plate modules are usually supplied by a vendor, it is advisable to have the vendor optimize the design in accordance with the particular configurations of plates supplied, particularly if a process performance guarantee is desired for the unit.

The information required for retrofitting existing separators includes existing separator geometry, basin water levels, influent quality, specific gravity of the oil and water phases at a given design temperature, and desired effluent quality.

SECTION 4—PARALLEL–PLATE SEPARATORS [6, 7, 8, 9]

4.1 General

4.1.1 INTRODUCTION

The efficiency of an oil–water separator is inversely proportional to the ratio of its discharge rate to the unit's surface area. A separator's surface area can be increased by the installation of parallel plates in the separator chamber. The resulting parallel-plate separator will have a surface area increased by the sum of the horizontal projections of the plates added. In cases where available space for a separator is limited, the extra surface area provided by a more compact parallel-plate unit makes the parallel-plate separator an attractive alternative to the conventional separator. Flow through a parallel-plate unit can be two to three times that of an equivalent conventional separator. According to vendors, the spatial requirements of oil–water separators can be reduced up to twofold on width and tenfold on length when a parallel-plate unit is used in place of a conventional one. Current refinery experience using parallel-plate separators on a large scale is not very extensive, however.

In addition to increasing separator surface area, the presence of parallel plates may decrease tendencies toward short-circuiting and reduces turbulence in the separator, thus improving efficiency. The plates are usually installed in an inclined position to encourage oil collected on the undersides of the plates to move toward the surface of the separator, whereas sludge collected on the plates will gravitate toward the bottom of the separator. To improve oil and sludge collection, the plates are usually corrugated. For downflow separators (see 4.2), vertical gutters adjacent to the plates allow segregation of the separated oil and sludge fractions from the influent stream; these vertical gutters are located at both ends of the plate pack. At the lower (effluent) end of the plate pack, the vertical gutters are placed adjacent to the "valleys" in the corrugated plates to help channel sludge downward. At the higher (influent) end of the plate pack, these gutters are placed adjacent to the "peaks" in the corrugated plates to help convey oil to the surface.

Oil collected from parallel-plate systems is said to have a lower water content than that removed from conventional separators, and the overall effluent oil content has been reported to be up to 60 percent lower for parallel-plate systems, with a higher proportion of small oil droplets recovered [6].

4.1.2 DESIGN

Typical ranges for the basic design variables of parallel-plate separation are given in Table 2.

Even with the knowledge of acceptable values for these separator design parameters, it is difficult, if not impossible, to specify a set procedure for the detailed design of parallel-plate separator systems. Manufacturers have empirically determined that certain plate-inclination, flow-pattern, and spacing configurations are most effective at removal of free oil over a given range of oily-wastewater conditions. Although in practice, a design range is used for these variables, as shown in Table 2, the values used can only be empirically justified. Refinery and vendor experience is the best basis for choosing a value for these empirical parameters that is appropriate for the wastewater being treated.

The determination of the surface area required for the plate pack and the number of packs needed is theoretically based and is standard for most parallel-plate configurations. A procedure for determining these parameters is given in 4.1.3.

4.1.3 WASTEWATER CHARACTERISTICS REQUIRED FOR SEPARATOR SIZING

In general, the parameters used for design of conventional separators are also used for sizing of parallel-plate systems: maximum (design) wastewater flow, specific gravity and viscosity of the wastewater's aqueous phase, and specific gravity of the wastewater oil. An oil-globule size distribution is also useful to determine a design oil-globule size, but in the absence of such data, a design globule diameter of 60 microns can be assumed. Conventional oil–water separators are designed to achieve complete capture of oil globules 150 microns and larger in diameter. Because of the greatly increased effective surface area of parallel-plate separators, they have been designed to achieve satisfactory effluent quality based on complete removal of oil globules 60 microns and larger in diameter. As with conventional separators, wastewater flow should include primarily process flow, with allowance for stormwater flow and refinery expansion where appropriate. The oil's specific gravity should reflect cold-weather conditions.

4.1.4 PARALLEL-PLATE SURFACE AREA [10, 11]

Several equations have been set forth for sizing the surface area of parallel plates. In general, their basis is Stokes'

Table 2—Typical Ranges for the Basic Design Variables of Parallel-Plate Separation

Variable	Range
Perpendicular distance between plates	0.75–1.5 inches
Angle of plate inclination from the horizontal	45°–60°
Type of oil removed	Free oil only
Direction of wastewater flow	Crossflow, downflow

law. As with conventional separators, the oil globules' rise rate can be equated with the surface-loading rate (Q_m/A_H), assuming a design mean oil-globule diameter of 60 microns:

$$Q_m / A_H = 0.00386[(S_w - S_o)/\mu] \qquad (10)$$

Where:

Q_m = design flow, in cubic feet per minute.
A_H = horizontal separator area, in square feet.
S_w = specific gravity of the wastewater's aqueous phase (dimensionless).
S_o = specific gravity of the wastewater's oil phase (dimensionless).
μ = wastewater's absolute (dynamic) viscosity, in poise.

Solving Equation 9 for A_H provides the total surface area required to separate oil globules with a design diameter of 60 microns from the wastewater under a given set of influent conditions.

The number and area configuration of plates required, in conjunction with the open (not plate-filled) surface area of the separator (if significant), comprise the total required surface area, A_H. Owing to the great variability among manufacturers with respect to plate size, spacing, and inclination, it is strongly recommended that a vendor be consulted for specification of these parameters.

Packaged parallel-plate separators are often not in a rectangular configuration. Sludge hoppers, tapered walls, and inlet and outlet arrangements to minimize turbulence vary from supplier to supplier. If a new parallel-plate installation or a major retrofit of an existing unit is contemplated, it may be appropriate to work closely with the equipment supplier during the preliminary and detailed engineering phases. Treatability pilot testing of parallel-plate units is available and highly recommended. Process problems (for example, oil and solids removal, clogging) can be diagnosed at this time and taken into account in equipment selection and separator design.

4.1.5 MAINTENANCE

Parallel-plate units may experience clogging problems if the plate inclination is too shallow or the plate-to-plate spacing is too narrow. It has also been reported that sand entering the plate system can collect at the entrance to the plate assembly and reduce flow through the lower plate sections. Should blockages develop, they may be cleared by removing the accumulated solids, flushing the plate pack with water or air, or mechanical cleaning. Operating and maintenance manuals and equipment suppliers should be consulted with regard to approved procedures. Solids accumulation and clogging should be considered before installation and designed for accordingly.

Parallel-plate packs do not generally clog if they are properly designed, installed, and maintained. If significant solids levels are expected, the plate inclination should be about 60 degrees, which exceeds the angle of repose of practically all solids encountered in such systems. A plate slope of 60 degrees and periodic blowdown of accumulated solids should help to avoid most parallel-plate separator plugging problems.

4.2 Construction Details

A variety of parallel-plate equipment configurations are commercially available. In the case of conventional separators retrofitted with parallel plates, few if any additional appurtenances are required in addition to those already present. New parallel-plate separators have a wide range of design features and may be purchased as packaged units, with oil- and sludge-drawoff equipment provided. Consequently, specific construction and appurtenance details are omitted from this subsection.

Two major types of parallel-plate separators are marketed: the cross-flow inclined plate and the downflow inclined plate. These are illustrated in Figures 17 and 18, respectively. Cross-flow separators that employ parallel plates oriented vertically and horizontally are also available, although there are few applications for them in refineries.

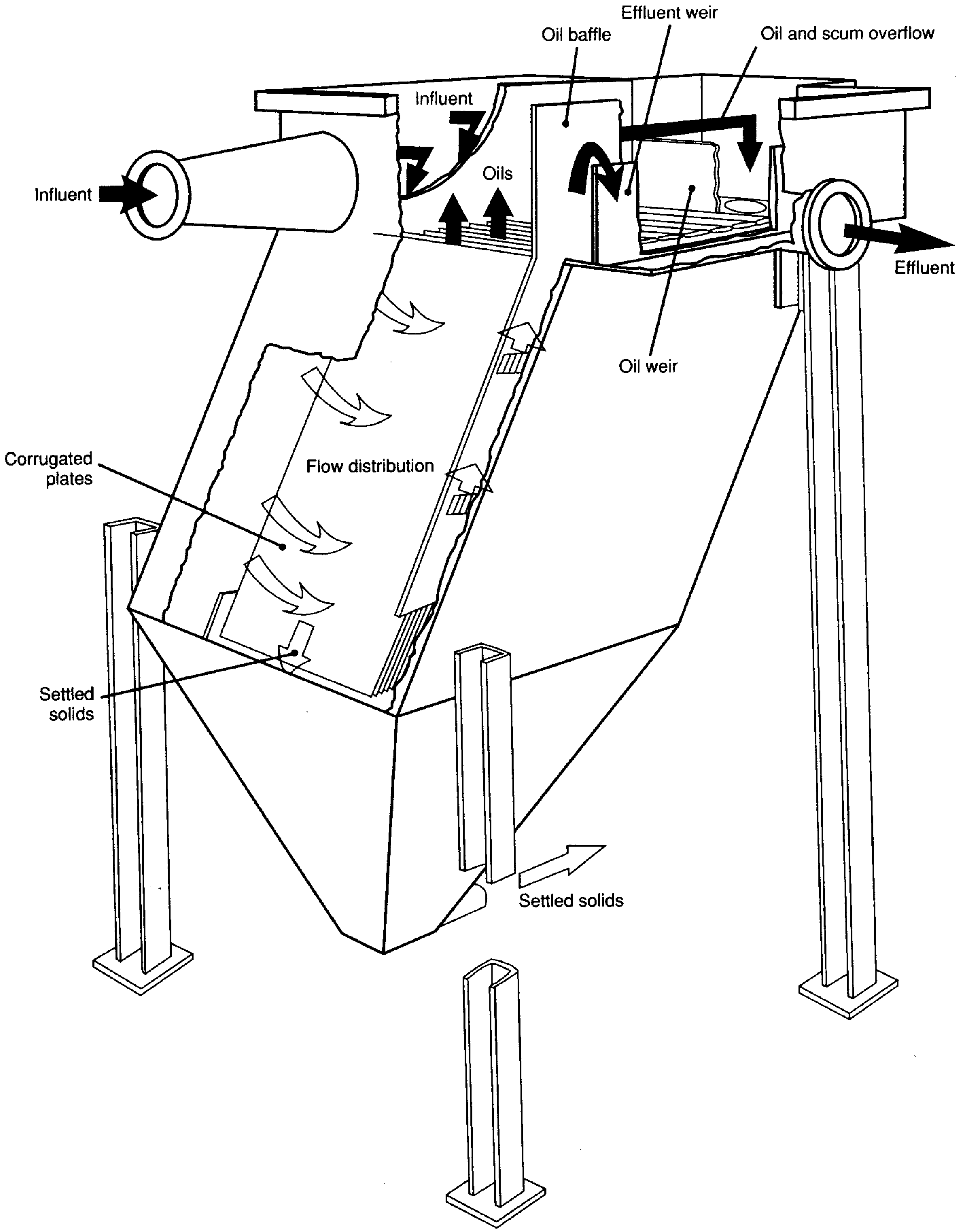
In a cross-flow separator, flow enters the plate section from the side and flows horizontally between the plates. Oil and sludge accumulate on the plate surfaces above and below the wastewater flowing between the plates. As the oil and sludge build up, the oil globules rise to the separator surface and sludge gravitates toward the separator bottom.

In a downflow separator, the wastewater flows down between the parallel plates, sludge deposited on the lower plates flows to the bottom of the separator, and oil accumulated beneath the upper plates flows countercurrent to the waste flow to the top of the separator.

4.3 Performance

Some interesting findings concerning the operation of parallel-plate separators emerge from the results of the 1985 API Refinery Survey. For five parallel-plate units with influent oil concentrations of 25–13,000 milligrams per liter (a mean of 3665 milligrams per liter), effluent concentrations ranged from 15 to 200 milligrams per liter (a mean of 79 milligrams per liter). Oils separated by these units had a mean specific gravity of 32°API, with a range of 15°API–56°API over a temperature range of 70°F–190°F. A summary of data on existing parallel-plate systems is given in Appendix C. A graphical representation of separator performance is shown in Figure 19. The effect of influent oil on effluent oil levels for parallel-plate units is given in Figure 16.

According to experimental studies [8, 10], parallel-plate separators can meet oil and grease limits of 50 milligrams per liter or less. Two factors may be responsible for perfor-



Note: Diagram courtesy of Envirex, Inc. Reprinted with permission.

Figure 17—Cross-Flow Parallel-Plate Separator

mance that exceeds this level: the emulsified- or dissolved-oil content of the wastewater, and nonoptimal separator performance resulting from deviation of the wastewater from the design basis. Flow surges can also diminish the efficiency of parallel-plate separators, as can solids buildup or plate clogging as a result of high solids loadings or waxy crudes.

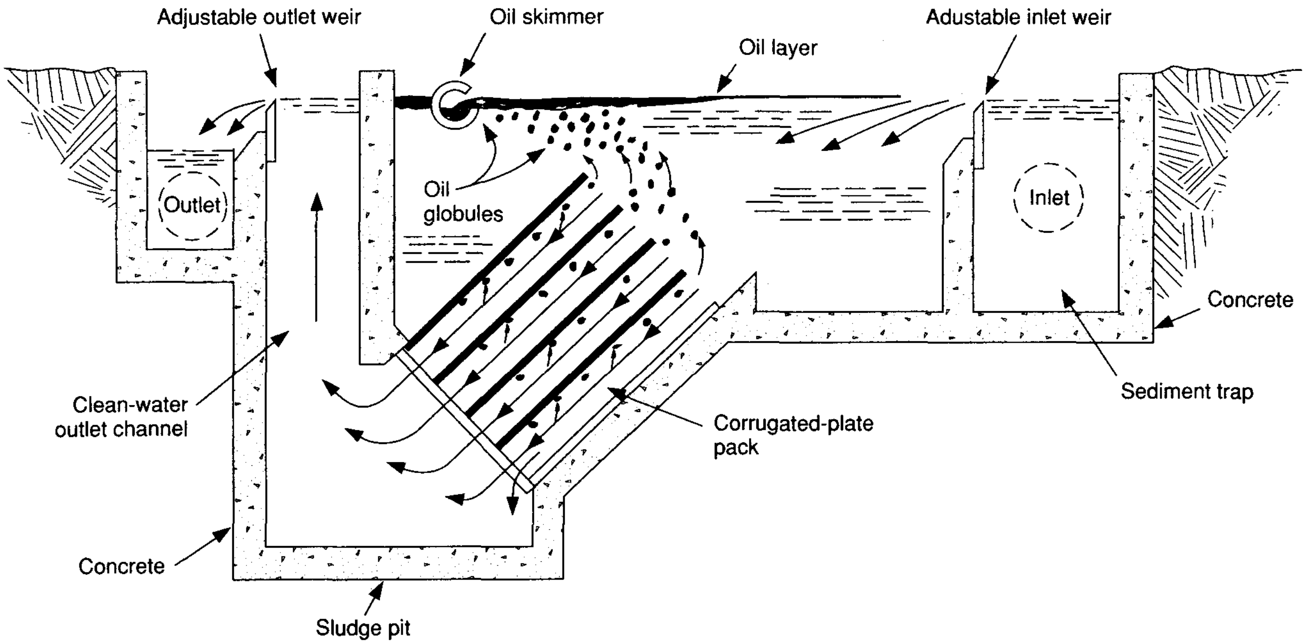


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Figure 18—Downflow Parallel-Plate Separator

The spacing of the plates and their angle of inclination ranged from 0.75 to 1.5 inches and from 45 to 90 degrees (vertical), respectively. Corrugated solid plates were uniformly used. Gravity feed to the separator was employed most frequently. Influent distribution generally consisted of an influent jet or set of nozzles followed by slotted baffles. Flow with respect to the plate packs was either cross-flow or downflow. Oil that collected at the surface of the separator was removed via overflow weirs or skimmer devices (for example, slotted pipe). Sludge accumulated at the separator bottom was either manually removed (for example, by vacuum truck) or concentrated for subsequent removal via sludge pumps or gravity flow.

Of seven-parallel plate systems reported on in the survey, five had no solids-removal devices preceding the separator. Nevertheless, no significant problems with clogging were noted. The lack of problems with clogging can be attributed primarily to preventive maintenance. In general, depending on the solids content of the influent stream, the parallel-plate packs were cleaned once or twice a year, according to survey respondents, to forestall problems with clogging.

SECTION 5—OPERATION AND MAINTENANCE OF OIL–WATER SEPARATORS

Since oil–water separators are relatively simple devices, there is sometimes a tendency to take them for granted and to devote all of one's attention to more complex wastewater treatment steps downstream of the separator. Doing so can be a mistake, because the oil–water separator is the first line of defense protecting the more sensitive downstream treatment steps from high levels of oil that could seriously disrupt their operation.

It is far better to monitor separator performance on a routine basis and make periodic minor adjustments than to wait until a serious problem develops that requires a major troubleshooting effort. Separator troubleshooting needs to be considered in conjunction with the type of waste treatment facilities downstream. It may not be economical to achieve separator performance that approaches theoretically optimal levels if downstream air flotation or biological treatment can readily tolerate or treat the oil levels historically present in the oil–water separator effluent.

Past operational data provide one of the best indicators for controlling present operations. To ensure good control, it is advisable to routinely record the quantity and characteristics of both the oil and the sludge that are removed from the separator. Oil should be periodically checked for specific gravity, and sludge for percent solids. The oil concentration of the separator effluent should also be measured periodically. An occasional API test for determination of susceptibility to settling (see 2.1.2.2 and Appendix B) is also helpful in that it allows one to compare actual performance with the best that can reasonably be expected.

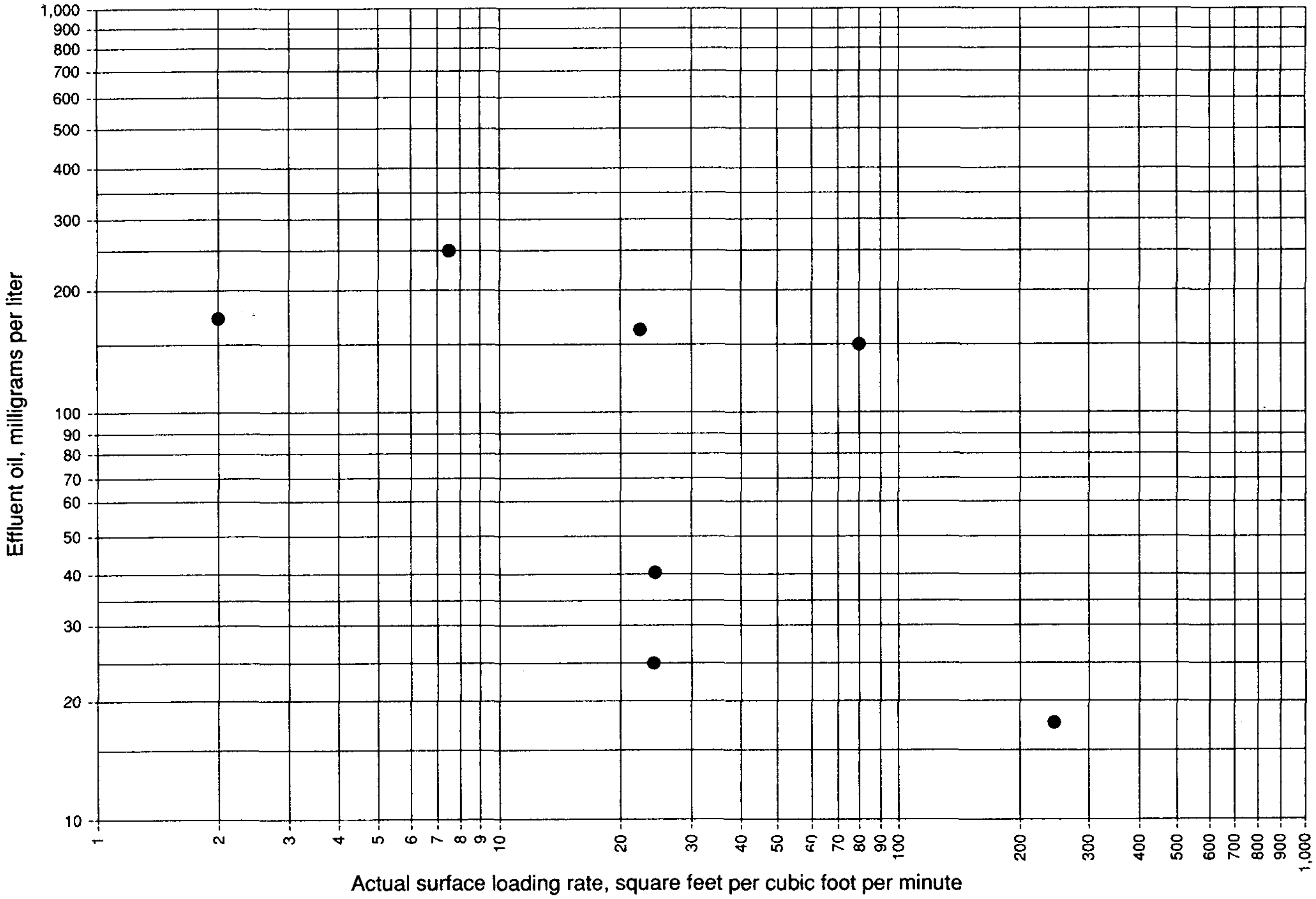
Conscientious operator attention cannot be overemphasized. Experience has shown that oil–water separator operations, such as oil skimming and sludge removal, may be difficult to automate completely with satisfactory results. Manual control by skilled operators may be preferable. If operations are automated, frequent and routine operator surveillance is recommended.

Good communications between the separator operator and process operators, as well as between the separator operator and the other wastewater treatment system operators is imperative, because the separator operator is often the first to see signs of impending problems stemming from major changes in the flow of process wastewater to the separator.

The most frequently encountered separator operational problems are as follows:

a. Mechanical failures of flight skimmers or scrapers caused by foreign objects such as tools, gloves, rags, and the like falling into the separator basin and getting caught in the flight mechanism.
b. Mechanical failure of flight scrapers caused by buildup of grit or silty sludge deposits on the bottom and edges of the separator chambers.
c. For separators with sludge-removal pumps, plugging of pump suction lines with foreign matter and silt, as well as failures of pump seals.
d. Debris and solids floating in the oil layer, causing problems with operation of the oil skimmer.
e. Excessive water being removed by the oil skimmer.
f. Solids-removal problems at the upstream bar screen.
g. For parallel-plate separators, plugging of the plate chambers with buildup of solids and foreign matter.
h. Buildup and discharge of oil as a result of infrequent skimming operations.

It is apparent that many of the problems are associated with solids buildup and solids removal. It is significant that nearly one-half of the separators responding to the API survey had no mechanical devices installed permanently within



Note: The data in this figure are taken from the 1985 API Refinery Survey.

Figure 19—Performance of Parallel-Plate Separators

the separator for the collection and removal of sludge. It should also be noted that most of the separators surveyed were more than 15 years old. Some early conventional separator designs [12] did not include sludge-removal devices; instead, periodic shutdown, cleaning, and sludge removal were accomplished with vacuum or pumping devices or with clamshell-bucket equipment. The nonmechanical route to solids removal is simple and appears to work quite satisfactorily in a large number of refineries, where solids loads, flow variability, and separator size are factored into sludge-removal operations. However, installation of covers and stricter effluent limits may make manual sludge removal less desirable. Parallel-plate separators can also be periodically drained as needed, and the plate chambers sprayed with a water jet to remove solids buildup; however, a means of removing sludge from the separator is also needed.

Although sludge pumps are widely used in municipal and industrial applications, some refiners have found them unsatisfactory for removing solids from separators. These refineries reported pump failure rates that were higher than expected because of the erosive effect of silt. The pumps were also reported to draw water along with the sludge. These chronic problems stemming from debris and abrasive solids underscore the importance of good grit collection and trash racks upstream of the separator, regardless of the type of sludge-removal system employed. The problems encountered in the use of sludge pumps for solids removal are thought to be partly responsible for the continued use of nonmechanical sludge-removal methods. It should be noted that sludge pumps can be used successfully in oil-water separator applications where proper preseparator solids removal is employed.

For oil skimming, the slotted-pipe rotatable skimmer gives satisfactory performance, provided that it is properly used by a diligent operator. Rotary-drum skimmers generally also work fairly well, though some problems have been reported with solids and foreign matter interfering with the clean scraping of the doctor (rubber scraper) blades that divert oil to the recovery channel. Degradation of rubber skimmer parts has also been noted.

The area around the separator should be kept free from debris and other objects that could fall or blow into the separator. Employees working around the separator should be encouraged to report cases of dropped tools, rags, and the like, since even a small amount of debris can affect the movement of skimmer and scraper flights.

All mechanical moving parts should be kept clean and properly lubricated. It is particularly important to keep exposed gear mechanisms heavily greased.

Separators equipped with covers can experience a variety of problems, including cover degradation, pontoon submergence, and shifting of the cover out of position during very high flows. These types of problems can usually be avoided by means of proper design and selection of appropriate construction materials.

SECTION 6—REFERENCES

1. "Investigation of the Behavior of Oil–Water Mixtures in Separators" (final report for the period June 1948 to June 1951), University of Wisconsin, Engineering Experiment Station for the Hydraulic and Sanitary Engineering Laboratory, Madison, August 1951.

2. "Methods for Chemical Analysis of Water and Wastes" (EPA-600/4-79-020), U.S. Environmental Protection Agency, Washington, D.C., 1983.

3. *Standard Methods for the Examination of Water and Wastewater,* 16th edition, American Public Health Association/American Water Works Association/Water Pollution Control Federation, Alexandria, Va., 1985.

4. T. R. Camp, "Sedimentation and the Design of Settling Tanks" (Paper 2285), *Transactions of the American Society of Civil Engineers,* 1946, Volume 111, pp. 895–958.

5. "Reaction Jet Inlets" (summary report on project sponsored by API), University of Wisconsin, Madison, 1962.

6. J. J. Brunsmann, J. Cornelissen, and H. Eilers, "Improved Oil Separation in Gravity Separators," *Journal of the Water Pollution Control Federation,* 1962, Volume 34, Number 1, pp. 44–55.

7. "Tilted-Plate Separator Effortlessly Purifies Water," *Chemical Engineering,* 1969, Volume 76, Number 2, pp. 102–104.

8. E. C. Shaw and W. L. Caughman, Jr., The Parallel Plate Interceptor, *NLGI Spokesman,* 1970, Volume 33, Number 11, pp. 395–399.

9. S. J. Thomson, "Report of Investigation on Gravity-Type Oil–Water Separators," *Proceedings of the 28th Industrial Waste Conference,* Purdue University, 1973, pp. 558–563.

10. G. J. Iggleden, "The Design and Application of Tilted Plate Separator Oil Interceptors, *Chemistry and Industry,* November 4, 1978, pp. 826–831.

11. J. G. Miranda, "Designing Parallel-Plate Separators," *Chemical Engineering,* 1977, Volume 84, Number 2, pp. 105–107.

12. *Manual on Disposal of Refinery Wastes,* American Petroleum Institute, New York, 1930.

13. W. N. Bond, "Bubbles and Drops and Stokes' Law, *The Philosophical Magazine,* November 1927, Series 7, Volume 4, Number 24, pp. 889–898.

14. Method 734, *Susceptibility to Oil Separation: STS Number,* American Petroleum Institute, New York, 1953.

APPENDIX A—DERIVATION OF BASIC EQUATIONS FOR DESIGN OF OIL–WATER SEPARATORS

A.1 Terminal Velocity of Oil Globules in Water

The basic principles of separation by gravity differential can be expressed mathematically and applied quantitatively. When a particle is allowed to move freely in a fluid and is subjected to gravitational force, its rising or settling velocity with respect to the fluid becomes a constant when the resistance to motion equals the weight of the particle in the fluid. In other words, the resistance to motion of a particle in a liquid medium is equal to the effective weight of the particle when the terminal velocity has been reached, namely, when the acceleration caused by gravity becomes zero. The general equation for this resistance, first proposed by Newton, is as follows:

$$D_f = CA\left(\frac{\rho_w V^2}{2}\right) \qquad \text{(A-1)}$$

Where:

D_f = particle's resistance to motion in a liquid medium, in dynes.
C = coefficient of drag (dimensionless).
A = projected area of the oil globule, in square centimeters.
ρ_w = density of water, in grams per cubic centimeter.
V = terminal velocity of the oil globule in water, in centimeters per second.

The equation for the effective weight of the particle is as follows:

$$W = \left(\frac{\pi D^3}{6}\right)(\rho_w - \rho_o)g \qquad \text{(A-2)}$$

Where:

W = effective weight of the oil globule in water, in dynes.
D = diameter of the oil globule, in centimeters.
μ_o = density of the oil globule, in grams per cubic centimeter.
g = acceleration caused by the force of gravity
= 981 centimeters per second squared.

Equating Equations A-1 and A-2,

$$CA\left(\frac{\rho_w V^2}{2}\right) = \left(\frac{\pi D^3}{6}\right)(\rho_w - \rho_o)g \qquad \text{(A-3)}$$

Inasmuch as for a sphere,

$$A = \frac{\pi D^2}{4}, \qquad \text{(A-4)}$$

the rate of rise is as follows:

$$V = \sqrt{\left(\frac{4D}{3}\right)\left[\frac{(\rho_w - \rho_o)g}{C\rho_w}\right]} \qquad \text{(A-5)}$$

The equation for the resistance to motion of a small spherical particle at its terminal velocity is as follows:

$$D_f = 3\pi\mu VD \qquad \text{(A-6)}$$

Where:

μ = absolute viscosity of wastewater at the design temperature, in poises.

If W in Equation A-2 is equated to D_f in Equation A-6, a new expression for V is obtained. By the substitution of V_r, the oil globules' velocity of rise (in centimeters per second), for the general term V, the well-known form of Stokes' law for the terminal velocity of spheres in a liquid medium becomes applicable to the rate of rise of oil globules in water:

$$V_r = \left(\frac{g}{18\mu}\right)(\rho_w - \rho_o)D^2 \qquad \text{(A-7)}$$

Equation A-7 should theoretically include a deformation coefficient that depends on the relative viscosities of the oil and the water; however, in practice, the coefficient is not required to estimate the rate of rise of small oil globules in wastewater.

Note: Theoretically, consideration should be given to the deformation of an oil globule as it rises through a liquid medium, because of a change of shape caused by its contact with the liquid through which it is rising. This change of shape results from internal flow so that the particle's resistance to motion is minimized and a higher rise rate results. W. N. Bond [13] has expressed this effect in terms of the viscosities of the particle and the medium as follows:

$$C_v = \frac{\frac{2}{3} + \frac{\mu_1}{\mu_2}}{1 + \frac{\mu_1}{\mu_2}}$$

Where:

C_v = deformation coefficient theoretically applicable to Equation A-7 (dimensionless); see the following equation.
μ_1 = absolute viscosity of the particle, in poises.
μ_2 = absolute viscosity of the medium, in poises.

If this correction for internal flow is applied to equation A-7, Stokes' law for determining the rate of rise of an oil particle in water would become the following:

$$v_t = \left(\frac{1}{C_v}\right)\left(\frac{1}{18}\right)\left(\frac{g}{\mu}\right)(\rho_w - \rho_o)D^2$$

Where:

v_t = rise rate of oil globule (0.015 centimeter in diameter) in wastewater, in feet per minute.

However, in the application of this equation to the design of wastewater separators,the factor $1/C_v$ may be omitted for practical purposes, because its value is very close to unity for the viscosities of oil to be separated from refinery wastewaters.

Equations A-6 and A-7 are strictly correct only when the rising particle's Reynolds number (based on the particle diameter) is less than 0.5. For the range of Reynolds numbers resulting from the computations in this chapter (all substantially less than unity), however, the deviation from Stokes' law is negligible for design purposes.

A.2 Size and Gravity of Oil Globules

The applicability of Equation A-7 to oil globules in wastewater has been investigated. From the results of experiments and from plant operating data, it has been determined that the design of wastewater separators should be based on the rise rate of oil globules with a diameter of 0.015 centimeter.

With a value of 0.015 for D in Equation A-7, the rise rate of such oil globules in wastewater may be expressed as follows:

$$v_t = 0.0241\left(\frac{S_w - S_o}{\mu}\right) \tag{A-8}$$

Where:

v_t = rise rate of oil globule (0.015 centimeter in diameter) in wastewater, in feet per minute.
S_w = specific gravity of wastewater at the design temperature of flow.
S_o = specific gravity of oil in wastewater at the design temperature of flow.

Note: S_w and S_o are specific gravities and are nearly the same numerically but differ dimensionally from ρ_w and ρ_o, which they replace.

To check the dimensions of this formula, it is necessary to note that the number 0.0241 was obtained from dimensional factors and therefore has the dimensions of its factors, which are as follows:

$$\left(\frac{981\ \text{cm}}{\text{sec}^2}\right)\left(\frac{1}{18}\right)\left(\frac{1\ \text{ft}}{30.5\ \text{cm}}\right)\left(\frac{60\ \text{sec}}{1\ \text{min}}\right) \times \left[\left(\frac{\text{g}}{\text{cm}^3}\right)(0.000225\ \text{cm}^2)\right] = \frac{(0.0241)(\text{g})(\text{ft})}{(\text{sec})(\text{min})(\text{cm})}$$

A.3 Derivation of Equation for Separator Length

Separator length is calculated from the following equation:

$$L = F\left(\frac{\sqrt{H}}{\sqrt{t}}\right)d \tag{A-9}$$

The basic equations used to derive the equation for separator length are as follows:

$$A_H = \frac{FQ_m}{\sqrt{t}} \tag{A-10}$$

$$A_c = \frac{Q_m}{\sqrt{H}} \tag{A-11}$$

$$A_c = dBn \tag{A-12}$$

Equation A-9 is derived from Equations A-10, A-11, and A-12 as follows:

$$\begin{aligned} L &= \frac{A_H}{Bn} \\ &= \frac{A_H}{\frac{A_c}{d}} \\ &= \frac{A_H d}{A_c} \\ &= \frac{\frac{FQ_m}{\sqrt{t}}d}{\frac{Q_m}{\sqrt{H}}} \\ &= F\left(\frac{\sqrt{H}}{\sqrt{t}}\right)d \end{aligned}$$

Where:

A_H = total separator surface area.
L = length of separator channel.
B = width of separator channel.
n = number of separator channels.
F = turbulence and short-circuiting factor (dimensionless).
Q_m = total design flow to the separator.
$\sqrt{t}$ = separator's surface-loading rate.
A_c = separator's total cross-sectional area.
$\sqrt{H}$ = separator's horizontal velocity.
d = depth of separator channel.

APPENDIX B—DETERMINATION OF SUSCEPTIBILITY OF SEPARATION

Note: This procedure was published for the first time in 1953 [14].

B.1 Scope

This method describes a procedure for determining the feasibility of removing suspended oil from effluent wastewater from a petroleum refinery by means of a separator designed on the principle of gravity-differential separation.

Note: The test described in this appendix is not to be used indiscriminately as a standard of separator efficiency, because the separation period specified will show a more complete separation than can be obtained in a full-scale separation installation of practical size.

B.2 Definition

The *susceptibility to separation (STS) number* is the oil content, in parts per million, of the separated water after the specified settling period.

B.3 Outline of Method

A sample of the wastewater stream taken under conditions of minimum agitation is allowed to settle in a separatory funnel at the stream temperature for 30 minutes. The solids are then withdrawn, and the oil content of the remaining water is determined.

B.4 Apparatus

The apparatus used to determine susceptibility of separation is a globe-shaped separatory funnel with a capacity of 6 liters.

B.5 Sampling Procedure

The sample is collected as described in B.6. As soon as the sample is taken, the test should be continued immediately, in accordance with B.6.

Note : For an existing separator, the selection of the sampling point is determined by the objectives of the test. For a proposed separator, the sampling point should be as close as possible to the location of the proposed unit's entrance. To locate sources of substances that interfere with oil–water separation, samples should be obtained near the point of confluence of the suspected streams.

B.6 Procedure

B.6.1 Place the separatory funnel in a bath maintained at a constant temperature within 2°F of the stream temperature and allow the sample to settle for 15 minutes under static conditions. Rotate the funnel gently to facilitate the collection of settled solids or heavy oil in the bottom of the funnel cone. Return the funnel to the bath and allow the sample to settle quietly for an additional 15 minutes.

B.6.2 At the end of the 30-minute settling period, carefully withdraw all the accumulated sludge and sediment, including the lower interface, and discard them. Then remove the amount of sample required to determine oil content, following the methods described in 2.1.2.

B.7 Calculation

The susceptibility to separation number is equal to the oil content of the separated water phase, expressed in parts per million at the specified temperature.

APPENDIX C—SELECTED RESULTS: 1985 API OIL–WATER SEPARATOR SURVEY

Table C-1—Selected Results of 1985 API Oil–Water Separator Survey: Conventional Separators

No. of Flow Channels	Length (feet)	Total Width (feet)	Water Depth (feet)	Actual Depth-to-Width Ratio	Actual Hydraulic Retention Time (hours)	Flow (gallons per minute)		Velocity (feet per minute)		Surface Area/Flow Ratio (square feet per cubic foot per minute)		Temperature (°F)	Specific Gravity of Oil	Influent Oil (milligrams per liter)	Effluent Oil (milligrams per liter)	Percent Process Water	Age (years)	Cover?
						Design	Actual	Design	Actual	Design	Actual							
1	23	8	3	0.38	0.7	100	70	0.6	0.6	14	14	130	0.94	1,000	75	70	39	
1	74	15.5	5.5	0.35	6.2	200	130	0.3	0.2	42	67	140	0.82	252	10–15	75	15	N
2	75.5	40	5	0.25	7.6	360	245	0.24	0.17	64	91	82	0.88	4.6%[a]	45	65	35	Y[b]
2	50	23	3.4	0.3	1.2		400		0.7		22	113	0.86	2%	500±	80	30	Y[b]
2	105	30	6	0.4	19	500	125	0.37	0.09	47	189	[c]	0.8			98	40	Y[b]
2	38	20	2.17	0.22	0.5	600	380	1.9	1.2	9.5	15	115	0.82			55	26	N
2	59	26	9.1	0.7	3		580		0.33		20	120	0.84			60	35+	Y[d]
1	33.25	20	13.4	0.67	2.2	700	500	0.35	0.25	7.1	10	95	0.88	10,000–25,000	100–2,000	70	37	Y[d]
2	48	22	5.0			1,525	375					105		6,200	180		17	Y[b]
2	30	22	8.5	0.77	2	750	325	0.53	0.22	6.6	15	105	0.87	6,300	212	70	31	Y[b]
1	62	10	4	0.4	0.5	800	500	2.7	1.7	5.8	9.2	95	0.87	10,000–25,000	100–2,000	70	2	Y[d]
2	39	10	3.5	0.7	0.7	1,000	250	3.8	0.9	2.9	12	100	0.93	200	25	40	7	N
2	41	29	6	0.42	0.9	1,000	1,050	0.77	0.8	8.9	9	[c]	0.8			79	40	N[e]
3	81.6	38.25	2.67	0.21	3.5	1,000	300–500	1.3	0.4	23	78	95	0.85+	10%[f]	25–50	45	2	Y[d]
2	70	16	4	0.5	0.7	1,000	800	2.1	1.7	8.4	11	130	0.85	477	32	98	18	
2	46	20	5	0.5	0.5	1,500	1,200	2.0	1.6	4.6	6	90	0.89	3,000	400	25	20	Y[d]
1	48	11	5	0.45	0.9	760	575	1.9	0.9	5.2	11	105	0.85	6,200	180	70	17	
2	119.5	24	5.5	0.46	1.7	2,000	1,200	2.0	1.2	10.7	18	75	0.8	19,200	<30	75	18	N[e]
2	88	20	6	0.6	0.8	2,000	1,600–2,000	2.2	1.8	6.6	8	105			6,800	60	15	Y[b]
2	55	24	6.5	0.54	2.1	2,000	500	1.7	0.4	4.9	5	110				65	34	
2	67	40	9.16	0.46	3.8	2,000	800	0.73	0.3	10	25	70	0.87		<100	22	37	
1	145	12.7	7.1	0.56	2	2,500	800	3.7	1.2	5.5	17	75	0.93	50	<30	75	2	N[e]
3	104	60	8.5	0.42	6.6	2,500	1,800	0.65	0.47	18.7	26	75	0.9	200	100		10	
6	37	120	7.8	0.39	4.4	2,990	1,000	0.43	0.14	11.4	34	110	0.85	1,000	40	30–90	36	
2	100	36	4.5	0.25	1.6	3,000	1,250	2.5	1.0	9.0	22	125	0.92		150	54	6	
2	85	30	5	0.33	1.2	3,000	1,300	2.7	1.2	6.4	15	80	0.89		2,600	95	16	Y[d]
2	90	32	5	0.31	1.4	3,400	1,300	2.8	1.1	6.3	17	[c]	0.8			76	18	N[e]
3	70	60	7.7	0.38	0.8	6,000	4,120	1.7	1.5	5.4	6	100	0.85		100		35	Y[d]
2	55	30	6.25	0.42	4		325	1.9	1.2		15	120	0.9	200–300	100–150	75	30	
2	100.3	32.5	9	0.55	0.8	12,000	4,500	5.6	2	2	5.4	120	0.9	1%–11%[f]	90–325	60	50	
2	100	30	5	0.33	1.2	2,000	1,600	1.8	1.4	11.2	14	110		<2%	100–	89	8	Y[g]
2	46	30	6	0.4	1.2	2,200	850	1.5	0.63	5.2	12.1	125	0.88		190		30	N
2	65	30	5.5	0.37	1.6	2,000	850	1.6	0.69	7.3	17.2	125	0.88		50–300			
4	100	80	6.75			12,000	2,500						[h]	[i]	40		29	Y[d]
1	55	24	5.5			1,000	400–600					95–125		3.3%			34	Y[b]
4	158		9.5			8,000	2,400								80			Y[b]

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[a] Upstream of forebay.
[b] Float.
[c] Ambient.
[d] Fixed.
[e] Forebays only.
[f] By volume.
[g] Covered after questionnaire.
[h] 22°API–60°API.
[i] Not measured; removing approximately 200 barrels per day.

Table C-2—Selected Results of 1985 API Oil-Water Separator Survey: Parallel-Plate Separators

Flow (gallons per minute)		Plate Effective Area (square feet)	Surface Area/ Flow Ratio		Distance Between Plates (inches)	Plate's Angle of Inclination (degrees)	Direction of Flow	Oil's Specific Gravity (°API)	Temperature (°F)	Influent Oil (milligrams per liter)	Effluent Oil milligrams per liter)	Retrofit
Design	Actual		Design	Actual								
75	10–20	496	49.6	247.3	0.75	45	Crossflow	30–45	165–175	25	15–20	Y
—	720	2074	—	21.6	1.00	50	Crossflow	18–20	50–140	1244	161	N
500	145	465	7.0	24.0	1.32	90	Crossflow	20–30	150–190	50–60	20–30	N
900	250	66	0.6	2.0	1.50	45	—	15–70	120	—	100–250	N
500	125–175	1600	24.0	79.8	0.75	45	Downflow	25–35	70–90	13,000	100–200	Y
2400	740	2400	7.5	24.3	0.75	45	Crossflow	40–56	70–100	4,000	40	N
2200	800–1200	1000	3.4	7.5	0.75	45	Downflow	25–30	100–130	—	250	N

APPENDIX D—TEST FOR SPECIFIC GRAVITY OF OIL IN WASTEWATER

The following procedure is used to test for the specific gravity of oil in wastewater:

a. Take representative samples of the entire waste flow as close as possible to the entrance to the separator.

b. Break any agglomerates to release the oil they carry, and let the sample stand for 1 hour to allow settling.

c. Collect any oil that has gathered on the water's surface, centrifuge the oil, and determine the oil's specific gravity.

d. When enough data have been collected to establish a range of specific gravities, the upper limit of the range is the design value for specific gravity used in the design of the separator.

Note: *Specific gravity is used in its dimensionless form (not degrees API)* for separator design. Conversions from degrees API to specific gravity at a given design temperature are provided in Table D-1.

Table D-1—Oil-Density Variation with Temperature (15°API–35°API)

Degrees Fahrenheit	15°API	16°API	17°API	18°API	19°API	20°API	21°API	22°API	23°API	24°API
40	0.9730	0.9664	0.9600	0.9536	0.9473	0.9411	0.9350	0.9289	0.9230	0.9171
41	0.9726	0.9660	0.9596	0.9533	0.9470	0.9408	0.9347	0.9286	0.9227	0.9168
42	0.9723	0.9657	0.9593	0.9529	0.9466	0.9404	0.9343	0.9282	0.9223	0.9164
43	0.9719	0.9653	0.9589	0.9525	0.9462	0.9400	0.9339	0.9278	0.9219	0.9160
44	0.9716	0.9650	0.9586	0.9522	0.9459	0.9397	0.9336	0.9275	0.9216	0.9157
45	0.9712	0.9640	0.9582	0.9518	0.9455	0.9393	0.9332	0.9271	0.9212	0.9153
46	0.9709	0.9643	0.9579	0.9515	0.9452	0.9390	0.9329	0.9268	0.9209	0.9150
47	0.9705	0.9639	0.9575	0.9511	0.9448	0.9386	0.9325	0.9264	0.9205	0.9146
48	0.9702	0.9636	0.9572	0.9508	0.9445	0.9383	0.9322	0.9261	0.9202	0.9143
49	0.9698	0.9632	0.9568	0.9504	0.9441	0.9379	0.9318	0.9257	0.9198	0.9139
50	0.9694	0.9628	0.9564	0.9500	0.9437	0.9375	0.9315	0.9254	0.9195	0.9136
51	0.9691	0.9625	0.9561	0.9497	0.9434	0.9372	0.9311	0.9250	0.9191	0.9132
52	0.9687	0.9621	0.9557	0.9493	0.9430	0.9368	0.9307	0.9246	0.9187	0.9128
53	0.9684	0.9618	0.9554	0.9490	0.9427	0.9365	0.9304	0.9243	0.9184	0.9125
54	0.9680	0.9614	0.9550	0.9486	0.9423	0.9361	0.9300	0.9239	0.9180	0.9121
55	0.9677	0.9611	0.9547	0.9483	0.9420	0.9358	0.9297	0.9236	0.9177	0.9118
56	0.9673	0.9607	0.9543	0.9479	0.9416	0.9354	0.9293	0.9232	0.9173	0.9114
57	0.9669	0.9603	0.9539	0.9475	0.9412	0.9350	0.9289	0.9228	0.9169	0.9110
58	0.9666	0.9600	0.9536	0.9472	0.9409	0.9347	0.9286	0.9225	0.9166	0.9107
59	0.9662	0.9596	0.9532	0.9468	0.9405	0.9343	0.9282	0.9221	0.9162	0.9103
60	0.9659	0.9593	0.9529	0.9465	0.9402	0.9340	0.9279	0.9218	0.9159	0.9100
61	0.9655	0.9589	0.9525	0.9461	0.9398	0.9336	0.9275	0.9214	0.9155	0.9096
62	0.9652	0.9586	0.9522	0.9458	0.9395	0.9333	0.9272	0.9211	0.9152	0.9093
63	0.9649	0.9583	0.9519	0.9455	0.9392	0.9330	0.9269	0.9208	0.9149	0.9090
64	0.9645	0.9579	0.9515	0.9451	0.9388	0.9326	0.9265	0.9204	0.9145	0.9086
65	0.9641	0.9575	0.9511	0.9447	0.9384	0.9322	0.9261	0.9200	0.9141	0.9082
66	0.9638	0.9572	0.9508	0.9444	0.9381	0.9319	0.9258	0.9197	0.9138	0.9079
67	0.9634	0.9568	0.9504	0.9440	0.9377	0.9315	0.9254	0.9193	0.9134	0.9075
68	0.9631	0.9565	0.9501	0.9437	0.9374	0.9312	0.9251	0.9190	0.9131	0.9072
69	0.9628	0.9562	0.9497	0.9433	0.9370	0.9308	0.9247	0.9186	0.9127	0.9068
70	0.9624	0.9558	0.9494	0.9430	0.9367	0.9305	0.9244	0.9183	0.9123	0.9064
71	0.9621	0.9555	0.9491	0.9426	0.9363	0.9301	0.9240	0.9179	0.9120	0.9061
72	0.9617	0.9551	0.9487	0.9423	0.9360	0.9298	0.9237	0.9176	0.9116	0.9057
73	0.9614	0.9548	0.9484	0.9419	0.9356	0.9294	0.9233	0.9172	0.9112	0.9053
74	0.9610	0.9544	0.9480	0.9415	0.9352	0.9290	0.9229	0.9168	0.9109	0.9050
75	0.9606	0.9540	0.9476	0.9412	0.9349	0.9287	0.9226	0.9165	0.9105	0.9046
76	0.9603	0.9537	0.9473	0.9409	0.9345	0.9283	0.9222	0.9161	0.9102	0.9043
77	0.9599	0.9533	0.9469	0.9405	0.9342	0.9280	0.9219	0.9158	0.9099	0.9040
78	0.9596	0.9530	0.9466	0.9402	0.9338	0.9276	0.9215	0.9154	0.9095	0.9036
79	0.9593	0.9527	0.9463	0.9399	0.9335	0.9273	0.9211	0.9150	0.9091	0.9032
80	0.9589	0.9523	0.9459	0.9395	0.9332	0.9270	0.9208	0.9147	0.9088	0.9028
81	0.9585	0.9519	0.9455	0.9391	0.9328	0.9266	0.9204	0.9143	0.9084	0.9025
82	0.9582	0.9516	0.9452	0.9388	0.9324	0.9262	0.9200	0.9139	0.9080	0.9021
83	0.9578	0.9512	0.9448	0.9384	0.9321	0.9259	0.9197	0.9136	0.9077	0.9018
84	0.9575	0.9509	0.9444	0.9380	0.9317	0.9255	0.9194	0.9133	0.9074	0.9015
85	0.9572	0.9505	0.9441	0.9377	0.9313	0.9251	0.9190	0.9129	0.9070	0.9011
86	0.9568	0.9502	0.9438	0.9374	0.9310	0.9248	0.9187	0.9126	0.9067	0.9008
87	0.9565	0.9498	0.9434	0.9370	0.9306	0.9244	0.9183	0.9122	0.9063	0.9004
88	0.9561	0.9495	0.9430	0.9366	0.9303	0.9241	0.9180	0.9119	0.9060	0.9001
89	0.9558	0.9491	0.9427	0.9363	0.9299	0.9237	0.9176	0.9115	0.9056	0.8997
90	0.9555	0.9488	0.9424	0.9360	0.9296	0.9234	0.9173	0.9112	0.9053	0.8994
91	0.9551	0.9484	0.9420	0.9356	0.9292	0.9230	0.9169	0.9108	0.9049	0.8990
92	0.9547	0.9481	0.9416	0.9352	0.9289	0.9226	0.9165	0.9104	0.9045	0.8986
93	0.9544	0.9478	0.9413	0.9348	0.9285	0.9223	0.9162	0.9101	0.9042	0.8983
94	0.9541	0.9475	0.9410	0.9345	0.9282	0.9220	0.9159	0.9098	0.9039	0.8980
95	0.9537	0.9471	0.9406	0.9342	0.9279	0.9217	0.9156	0.9095	0.9035	0.8976
96	0.9534	0.9468	0.9403	0.9338	0.9275	0.9213	0.9152	0.9091	0.9032	0.8973
97	0.9530	0.9464	0.9400	0.9335	0.9272	0.9210	0.9149	0.9088	0.9028	0.8969
98	0.9526	0.9460	0.9396	0.9331	0.9268	0.9206	0.9145	0.9084	0.9024	0.8965
99	0.9523	0.9457	0.9393	0.9328	0.9265	0.9203	0.9142	0.9081	0.9021	0.8962
100	0.9520	0.9454	0.9389	0.9325	0.9262	0.9200	0.9138	0.9077	0.9018	0.8959

Table D-1—Continued

25°API	26°API	27°API	28°API	29°API	30°API	31°API	32°API	33°API	34°API	35°API	Degrees Fahrenheit
0.9113	0.9055	0.8998	0.8943	0.8888	0.8834	0.8780	0.8726	0.8674	0.8623	0.8571	40
0.9110	0.9052	0.8995	0.8939	0.8884	0.8831	0.8777	0.8723	0.8671	0.8620	0.8568	41
0.9106	0.9048	0.8991	0.8936	0.8881	0.8827	0.8773	0.8719	0.8667	0.8616	0.8564	42
0.9102	0.9044	0.8987	0.8932	0.8877	0.8823	0.8769	0.8715	0.8663	0.8612	0.8560	43
0.9099	0.9041	0.8984	0.8928	0.8873	0.8819	0.8765	0.8712	0.8660	0.8609	0.8557	44
0.9095	0.9037	0.8980	0.8924	0.8869	0.8815	0.8761	0.8708	0.8656	0.8605	0.8553	45
0.9092	0.9034	0.8977	0.8921	0.8866	0.8812	0.8758	0.8704	0.8632	0.8601	0.8549	46
0.9088	0.9030	0.8973	0.8917	0.8862	0.8808	0.8754	0.8701	0.8649	0.8598	0.8546	47
0.9085	0.9027	0.8970	0.8914	0.8859	0.8805	0.8751	0.8697	0.8645	0.8594	0.8543	48
0.9081	0.9023	0.8966	0.8910	0.8855	0.8801	0.8747	0.8694	0.8643	0.8591	0.8539	49
0.9078	0.9020	0.8963	0.8907	0.8852	0.8798	0.8744	0.8690	0.8639	0.8587	0.8535	50
0.9074	0.9016	0.8959	0.8903	0.8848	0.8794	0.8741	0.8687	0.8636	0.8584	0.8532	51
0.9070	0.9012	0.8955	0.8899	0.8844	0.8790	0.8737	0.8683	0.8632	0.8580	0.8528	52
0.9067	0.9009	0.8952	0.8896	0.8841	0.8787	0.8733	0.8679	0.8628	0.8576	0.8524	53
0.9063	0.9005	0.8948	0.8892	0.8837	0.8783	0.8729	0.8675	0.8624	0.8572	0.8520	54
0.9060	0.9002	0.8945	0.8889	0.8834	0.8780	0.8726	0.8672	0.8621	0.8569	0.8517	55
0.9056	0.8998	0.8941	0.8885	0.8830	0.8776	0.8722	0.8668	0.8617	0.8565	0.8513	56
0.9052	0.8994	0.8937	0.8881	0.8826	0.8772	0.8718	0.8664	0.8613	0.8561	0.8509	57
0.9049	0.8991	0.8934	0.8878	0.8823	0.8769	0.8715	0.8661	0.8609	0.8557	0.8505	58
0.9045	0.8987	0.8930	0.8874	0.8819	0.8765	0.8711	0.8657	0.8606	0.8554	0.8502	59
0.9042	0.8984	0.8927	0.8871	0.8816	0.8762	0.8708	0.8634	0.8602	0.8550	0.8498	60
0.9038	0.8980	0.8923	0.8867	0.8812	0.8758	0.8704	0.8650	0.8598	0.8546	0.8494	61
0.9035	0.8977	0.8920	0.8864	0.8809	0.8755	0.8701	0.8647	0.8595	0.8543	0.8491	62
0.9032	0.8974	0.8917	0.8861	0.8806	0.8752	0.8698	0.8644	0.8592	0.8540	0.8488	63
0.9028	0.8970	0.8913	0.8857	0.8802	0.8748	0.8694	0.8640	0.8588	0.8536	0.8484	64
0.9024	0.8966	0.8909	0.8853	0.8798	0.8744	0.8690	0.8636	0.8584	0.8532	0.8480	65
0.9020	0.8962	0.8905	0.8849	0.8794	0.8740	0.8686	0.8632	0.8580	0.8528	0.8476	66
0.9017	0.8959	0.8902	0.8846	0.8791	0.8736	0.8682	0.8629	0.8577	0.8525	0.8473	67
0.9013	0.8955	0.8898	0.8842	0.8787	0.8733	0.8679	0.8624	0.8573	0.8521	0.8469	68
0.9010	0.8952	0.8895	0.8839	0.8784	0.8729	0.8675	0.8621	0.8569	0.8517	0.8465	69
0.9006	0.8948	0.8891	0.8835	0.8780	0.8725	0.8671	0.8617	0.8565	0.8513	0.8461	70
0.9003	0.8945	0.8888	0.8831	0.8776	0.8722	0.8668	0.8614	0.8562	0.8510	0.8458	71
0.8999	0.8941	0.8884	0.8828	0.8773	0.8718	0.8664	0.8610	0.8558	0.8506	0.8454	72
0.8995	0.8937	0.8880	0.8824	0.8769	0.8714	0.8660	0.8606	0.8554	0.8502	0.8450	73
0.8992	0.8934	0.8877	0.8820	0.8765	0.8710	0.8656	0.8602	0.8550	0.8498	0.8446	74
0.8988	0.8930	0.8873	0.8817	0.8762	0.8707	0.8653	0.8599	0.8547	0.8495	0.8443	75
0.8985	0.8926	0.8869	0.8813	0.8758	0.8704	0.8650	0.8595	0.8543	0.8491	0.8439	76
0.8982	0.8923	0.8866	0.8810	0.8755	0.8701	0.8647	0.8592	0.8540	0.8488	0.8435	77
0.8978	0.8919	0.8862	0.8806	0.8751	0.8697	0.8642	0.8588	0.8536	0.8484	0.8432	78
0.8974	0.8916	0.8859	0.8802	0.8747	0.8693	0.8638	0.8584	0.8532	0.8480	0.8428	79
0.8970	0.8912	0.8855	0.8799	0.8743	0.8689	0.8635	0.8581	0.8529	0.8477	0.8424	80
0.8967	0.8909	0.8852	0.8795	0.8740	0.8686	0.8631	0.8577	0.8525	0.8473	0.8420	81
0.8963	0.8905	0.8848	0.8791	0.8736	0.8682	0.8628	0.8574	0.8521	0.8469	0.8416	82
0.8960	0.8901	0.8844	0.8788	0.8733	0.8679	0.8624	0.8570	0.8518	0.8466	0.8413	83
0.8957	0.8898	0.8840	0.8784	0.8729	0.8675	0.8620	0.8566	0.8514	0.8462	0.8409	84
0.8952	0.8894	0.8837	0.8781	0.8726	0.8672	0.8617	0.8563	0.8510	0.8458	0.8405	85
0.8950	0.8891	0.8834	0.8778	0.8722	0.8668	0.8613	0.8559	0.8506	0.8454	0.8401	86
0.8946	0.8887	0.8830	0.8774	0.8719	0.8665	0.8610	0.8556	0.8503	0.8451	0.8398	87
0.8942	0.8884	0.8827	0.8771	0.8715	0.8661	0.8606	0.8552	0.8499	0.8447	0.8395	88
0.8938	0.8880	0.8823	0.8767	0.8712	0.8658	0.8603	0.8549	0.8496	0.8443	0.8391	89
0.8935	0.8877	0.8820	0.8764	0.8708	0.8654	0.8599	0.8544	0.8492	0.8440	0.8388	90
0.8931	0.8873	0.8816	0.8760	0.8704	0.8650	0.8595	0.8540	0.8488	0.8436	0.8384	91
0.8928	0.8870	0.8813	0.8757	0.8701	0.8647	0.8592	0.8537	0.8485	0.8432	0.8380	92
0.8925	0.8867	0.8810	0.8754	0.8698	0.8643	0.8589	0.8534	0.8482	0.8429	0.8377	93
0.8922	0.8864	0.8806	0.8750	0.8694	0.8639	0.8585	0.8530	0.8478	0.8426	0.8374	94
0.8918	0.8860	0.8802	0.8746	0.8691	0.8636	0.8582	0.8527	0.8475	0.8422	0.8370	95
0.8915	0.8857	0.8799	0.8742	0.8687	0.8632	0.8578	0.8524	0.8472	0.8419	0.8367	96
0.8911	0.8853	0.8795	0.8739	0.8684	0.8629	0.8575	0.8520	0.8468	0.8415	0.8363	97
0.8907	0.8849	0.8792	0.8735	0.8680	0.8625	0.8571	0.8517	0.8465	0.8412	0.8360	98
0.8904	0.8845	0.8788	0.8732	0.8677	0.8622	0.8568	0.8514	0.8462	0.8409	0.8357	99
0.8900	0.8842	0.8785	0.8728	0.8673	0.8619	0.8565	0.8510	0.8458	0.8405	0.8353	100

Table D-1—Continued

Degrees Fahrenheit	15°API	16°API	17°API	18°API	19°API	20°API	21°API	22°API	23°API	24°API
101	0.9516	0.9450	0.9386	0.9321	0.9258	0.9196	0.9135	0.9074	0.9015	0.8956
102	0.9513	0.9447	0.9383	0.9318	0.9255	0.9193	0.9132	0.9071	0.9011	0.8952
103	0.9510	0.9443	0.9379	0.9315	0.9252	0.9189	0.9128	0.9067	0.9008	0.8949
104	0.9506	0.9439	0.9375	0.9311	0.9248	0.9186	0.9124	0.9063	0.9004	0.8944
105	0.9503	0.9436	0.9372	0.9308	0.9245	0.9183	0.9121	0.9060	0.9000	0.8940
106	0.9500	0.9433	0.9369	0.9305	0.9242	0.9180	0.9118	0.9057	0.8997	0.8937
107	0.9496	0.9430	0.9366	0.9302	0.9239	0.9177	0.9115	0.9054	0.8994	0.8934
108	0.9493	0.9426	0.9362	0.9298	0.9235	0.9173	0.9111	0.9050	0.8990	0.8930
109	0.9489	0.9423	0.9359	0.9295	0.9231	0.9169	0.9107	0.9046	0.8986	0.8926
110	0.9486	0.9419	0.9356	0.9291	0.9228	0.9166	0.9104	0.9042	0.8983	0.8923
111	0.9483	0.9416	0.9352	0.9288	0.9225	0.9163	0.9101	0.9039	0.8980	0.8920
112	0.9479	0.9412	0.9348	0.9284	0.9221	0.9159	0.9097	0.9035	0.8976	0.8916
113	0.9475	0.9409	0.9344	0.9280	0.9217	0.9155	0.9093	0.9032	0.8973	0.8913
114	0.9472	0.9406	0.9341	0.9277	0.9214	0.9152	0.9090	0.9029	0.8969	0.8909
115	0.9469	0.9402	0.9338	0.9274	0.9211	0.9148	0.9087	0.9025	0.8966	0.8906
116	0.9465	0.9399	0.9335	0.9271	0.9208	0.9145	0.9084	0.9022	0.8963	0.8903
117	0.9462	0.9396	0.9332	0.9268	0.9205	0.9142	0.9081	0.9019	0.8960	0.8900
118	0.9459	0.9393	0.9329	0.9265	0.9201	0.9138	0.9077	0.9016	0.8956	0.8896
119	0.9455	0.9389	0.9325	0.9261	0.9198	0.9135	0.9074	0.9012	0.8953	0.8893
120	0.9452	0.9386	0.9321	0.9257	0.9194	0.9131	0.9070	0.9008	0.8949	0.8889

Table D-1—Continued

25°API	26°API	27°API	28°API	29°API	30°API	31°API	32°API	33°API	34°API	35°API	Degrees Fahrenheit
0.8897	0.8838	0.8781	0.8724	0.8669	0.8615	0.8561	0.8506	0.8454	0.8401	0.8349	101
0.8893	0.8834	0.8777	0.8720	0.8665	0.8611	0.8557	0.8502	0.8450	0.8397	0.8344	102
0.8890	0.8831	0.8774	0.8717	0.8662	0.8607	0.8553	0.8498	0.8446	0.8393	0.8340	103
0.8886	0.8828	0.8771	0.8714	0.8659	0.8604	0.8550	0.8495	0.8442	0.8389	0.8336	104
0.8882	0.8824	0.8767	0.8710	0.8655	0.8600	0.8546	0.8491	0.8438	0.8386	0.8333	105
0.8879	0.8820	0.8763	0.8707	0.8652	0.8597	0.8542	0.8488	0.8435	0.8383	0.8330	106
0.8875	0.8817	0.8760	0.8703	0.8648	0.8593	0.8538	0.8484	0.8431	0.8379	0.8326	107
0.8872	0.8813	0.8756	0.8700	0.8644	0.8590	0.8535	0.8481	0.8428	0.8376	0.8322	108
0.8868	0.8810	0.8753	0.8696	0.8640	0.8586	0.8531	0.8477	0.8424	0.8371	0.8318	109
0.8865	0.8806	0.8749	0.8693	0.8637	0.8583	0.8528	0.8474	0.8421	0.8368	0.8315	110
0.8862	0.8803	0.8745	0.8689	0.8633	0.8579	0.8524	0.8470	0.8417	0.8364	0.8311	111
0.8858	0.8799	0.8742	0.8686	0.8630	0.8576	0.8521	0.8466	0.8413	0.8360	0.8307	112
0.8855	0.8796	0.8738	0.8682	0.8626	0.8572	0.8517	0.8462	0.8409	0.8356	0.8303	113
0.8851	0.8792	0.8735	0.8679	0.8623	0.8569	0.8514	0.8459	0.8406	0.8353	0.8300	114
0.8848	0.8789	0.8732	0.8676	0.8620	0.8565	0.8510	0.8455	0.8402	0.8349	0.8296	115
0.8844	0.8786	0.8729	0.8673	0.8617	0.8562	0.8507	0.8452	0.8399	0.8346	0.8293	116
0.8841	0.8783	0.8725	0.8669	0.8613	0.8558	0.8503	0.8448	0.8395	0.8342	0.8289	117
0.8837	0.8779	0.8722	0.8666	0.8610	0.8555	0.8500	0.8444	0.8392	0.8338	0.8285	118
0.8834	0.8776	0.8718	0.8662	0.8606	0.8551	0.8496	0.8441	0.8388	0.8335	0.8282	119
0.8830	0.8772	0.8714	0.8658	0.8602	0.8548	0.8493	0.8438	0.8385	0.8332	0.8279	120

1- 1300— 2/90— 1M (5D)
1-01400—10/92—2.5C (IE) C
1-01400— 1/94—2.5C (1E) U

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