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Revision Memo

- 12/99** Made minor editorial changes. Revised oil/water separation theory equations and detailed oil/water separation equations for API and parallel plate separators to consistent units. Added section on specific vendor information required to assist in the selection of separation equipment. Included information on improving the performance of existing separators. Modified parallel plate total perpendicular cross sectional area to show it is not a function of the angle of inclination. Revised sample design equations to reflect above changes.



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SCOPE

This section presents recommended process design considerations and procedures for primary oil / water separators. The primary oil / water separators covered in this section are:

- API Separators
- Parallel Plate Separators / Interceptors
- Skim Ponds (Tanks)
- Daburt Separator
- Package Oil / Water Separator
- Cyclone Separator
- Centrifuges

A gravity type separator will separate other undissolved materials, e.g., solids, if their densities differ from that of water. However, the separator is usually sized for the separation of dispersed oil droplets from water / wastewater.

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DEFINITIONS

Dissolved Oil

Dissolved or Soluble oil (particle size of less than 0.45 micron or that passing through a standard 0.45 micron lab glass fiber filter) 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.

Effective Area

Effective area of a separator refers to the horizontal projection of the separator plates.

Emulsified Oil

Emulsified oil is defined as small oil droplets (in the range of 5–50 micron diameter) that form a stable suspension in the water as a result of the predominance of interparticle forces over buoyant forces. The presence of fine particulates also contributes to emulsion formation and stabilization.

Oil and Grease

Oil and grease is a key indicator test for effluent compliance in the petroleum industry and is reported in units of ppm or mg/L. It measures the total of dissolved and suspended "oil" fractions extracted from a wastewater sample by an organic solvent, typically freon (trichlorotrifluoroethane) or other similar solvent. Caution should be used in interpreting the results of this test since it can measure naturally occurring organic compounds, which may give artificially high readings in the oil test. Specific test procedures may vary, according to government regulations. It is important to specify the lab method used along with data.

Parallel Plate Separators

The following acronyms are interchangeably used for parallel plate separators.

CPI	Corrugated Plate Interceptor
CPS	Corrugated Plate Separator
PPI	Parallel Plate Interceptor
PPS	Parallel Plate Separator (Pressurized Plate Separator)
TPI	Tilted Plate Interceptor

Rise Rate

The velocity at which oil droplets move toward the separator surface.

Settleable Solids

Settleable solids is the term applied to the material settling out of suspension within a defined period of 1 hour, using a special settling tube called an Imhoff cone.

Suspended Oil

Suspended or "Free " oil is in the form of discrete oil globules of a size sufficient to rise as a result of buoyant forces, forming an oil layer on top of the water. Under proper quiescent flow conditions, free oil can be removed by gravity separation. For example, an API separator is designed to remove free oil droplet with diameters greater than 150 microns. Some vendors of packaged plate separators claim to remove particle sizes less than 50 microns.

Total Suspended Solids

Total suspended solids is the amount of suspended matter as measured by filtering a known volume of wastewater and drying solids at 217°F (103°C) and is reported in units of ppm or mg/L. Inorganic particles such as clay or grit as well as organic particles (biological solids including algae) contribute to a waste stream's suspended solids concentration.

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BACKGROUND

Many refinery, petrochemical plant wastewater streams contain oil in three major forms: suspended (free), emulsified, and dissolved. A gravity type oil / water separator, e.g., API Separator, Parallel Plate Separator, is a specially designed container or device to provide flow conditions sufficiently quiescent so that particles of free oil rise to the water surface and coalesce into a separate oil phase. Primary oil / water separators are used to separate and recover for reuse the undissolved oil from water. They will not separate soluble substances, break down emulsions, or remove soluble compounds that contribute to the Biochemical Oxygen Demand (BOD). Separators also provide conditions that allow the settling of suspended solid particles.

Gravity separation of free oil is most widely applied wastewater treatment process in Exxon. API separators have been the standard for free oil removal for many years. Over the past two decades, newly developed "packaged" parallel plate gravity separators have been applied to many of the services previously reserved for the API separator.

Segregation of the wastewater streams can sometimes afford savings in separator construction, and often will result in an effluent containing less oil than it would contain if the streams were combined. For example, it may be feasible to segregate (1) oil-free wastewater (such stream as steam turbine condenser water, oil-free storm runoff water, once-through cooling water in C₅ and lighter service, and cooling tower blowdown in C₅ and lighter service); (2) oily cooling water (once-through cooling water in C₆ and heavier service); and (3) oily storm water; and (4) process water (such streams as desalter waters, tank water drawoffs, stripper condensate, pump gland cooling water, etc.).

Waste streams (1) and (2) (with the exception of storm runoff which can have a large accumulation of silt) contain little or no suspended matter, and whatever oil may be present is clean and readily separable. These streams can sometimes be treated in special-purpose, "clean water" separators, or sedimentation ponds. Mechanical sludge-removal equipment can usually be omitted from these special purpose separators.

The use of auxiliary or unit separators at various specific units in the plant is a valid waste management practice, and the installation of such auxiliary separators should be considered. Unit separators can provide early leak detection and correction, and potential reuse of "like-kind" products at the source. Their use reduces the oil load on the plant separator and may improve the quality of the final effluent. However, there may exist debits such as increase in number of pumps and spacing requirements. Therefore, appropriate wastewater management, including source reduction, recycle and reuse options, should carefully be analyzed before starting a new design or revamp of an existing facility to optimize separator size and performance.

Although the design procedure for oil / water separators and some general design considerations are given here, the design and construction of an oil / water separator installation or the modernization of an old one may present problems or require decisions based upon factors peculiar to a specific refinery's processing units, layout, and location.

SEPARATOR TYPES AND APPLICATION

DECISION TREE FOR PRIMARY OIL / WATER SEPARATOR SELECTION

A decision tree, **Figure 1**, has been provided to assist in the selection of the best primary oil / water separator according to the oil / water characteristics. Should the influent to the separator not meet the categories in the decision tree, refer to **Section XIX-A, Guidelines for Selecting Wastewater Treatment Systems**, for a broader selection.

GENERAL APPLICATIONS

Primary oil / water separators are used to remove gross amounts of free oil and suspended solids in process wastewaters. Typical inlet oil content ranges from 1,000 to 5,000 ppm (mg/L). The intent is to reduce the oil content to below about 50 to 100 ppm (mg/L) consistently and to recover the oil for recycle to the slop system. For some advanced primary oil / water separators, such as package separators and the Daburt separator, the effluent concentration has been determined to be as low as 10 to 20 ppm (mg/L), depending on the oil characteristics, such as oil droplet size. Typical effluent suspended solids content ranges from 20 to 200 ppm (mg/L).

The oil / water separation efficiency is influenced by a number of factors, the most significant of which are inlet flow rate, oil concentration, oil droplet size, and the specific gravity of the oil to be separated. In addition, the extent of emulsion in the feed can have a great impact on the performance of the separator. Oil in oil / water separators, whether free, dissolved, or emulsified, is affected by the pH and energy induced upstream of the separator. Centrifugal pumps should be avoided and high pH should also be avoided.

The specific applications for each major type of primary oil / water separator are briefly discussed below. **Table 1**, a summary of separators oil & solids removal, and **Table 2**, a relative cost summary, may also be helpful in deciding the primary oil / water separator type. The advantages and disadvantages for each separator are summarized in **Table 3**.

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SEPARATOR TYPES AND APPLICATION (Cont)

API SEPARATORS

The most common means of separating insoluble oil from water in refining and petrochemical wastewaters is the API (American Petroleum Institute) separator. The API separator consists of a rectangular concrete basin with multiple-channels (**Figure 2**) providing sufficient holdup time and quiescence to allow oil droplets to rise to the surface where they are skimmed away. Typically, this separator is set below grade, but depending on the topography of the site, above grade design may be considered for ease in sludge removal, and it should be covered to prevent volatile hydrocarbon emissions to the air.

An API separator is sized to provide sufficient residence time to allow an oil droplet 150 microns in diameter to rise from the bottom of the separator to the surface, thereby providing complete removal of droplets 150 microns and larger. Smaller droplets have a slower rise rate (per Stokes' law, rise velocity is proportional to the square of the diameter), hence they are only partially removed.

Influent water may contain an average of 1,000 to 5,000 ppm (mg/L) oil and a maximum of 10,000 to 50,000 ppm (mg/L). Effluent water oil content depends upon oil droplets size and size distribution, and upon the amount of emulsified and dissolved oil. With proper design, maintenance, and operation, the API separator effluent water oil content will usually be about 50 ppm (mg/L) or more, when measured by the oil and grease analysis.

PARALLEL PLATE SEPARATOR

- Parallel Plate Separator (PPS) is also commonly known as Parallel Plate Interceptor (PPI), Corrugated Plate Interceptor (CPI), Corrugated Plate Separator (CPS), or Tilted Plate Interceptor (TPI). These plate separators consist of a basin with numerous submerged parallel plates inclined about 45 – 60° in the direction transverse to flow (see **Reference 7**). Oil droplets rise beneath each plate, coalesce at the underside surface of each plate, and slide up the plate undersides to the edge of the basin, and from there rise to the water surface. Similarly, solids settle to each plate, agglomerate, and slide to the bottom of the basin. With PPS, oil drops need rise, at most, only the short distance between plates, rather than as far as the entire basin depth as with API separators. Therefore, much smaller residence time and hence greatly reduced basin dimensions are required as compared to API separators. Plate separators are generally designed to remove oil droplets larger than 60 microns compared to the 150 microns droplet size that can be removed by an API separator.

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 PPS an attractive alternative to the API separator.

Flow through a parallel unit can be two to three times that of an equivalent API separator of the same cross sectional area. 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 API separator.

A variety of parallel plate equipment configurations are commercially available. Two major types of parallel plate separators marketed are: the cross flow parallel plate and the downflow parallel plate. In a cross-flow separator (**Figure 3**), 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 (**Figure 4**), 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.

SKIM PONDS

A skim pond is a pond where wastewater is retained to allow oil, water, and sludge separation. They are generally located downstream of an oil / water separator, e.g., API separator, and are used as a polishing or secondary step to remove residual oil. Skim pond retention time can range from as low as 1 to 24 hours to a few months. After this period, oil skimmers and/or scraping devices are used to remove the surface oil or bottom sludges.

Uses of skim ponds are strongly dependent on the cost of land and environmental regulations. Since the ponds are not covered, hydrocarbon emissions, odors and underground contamination are issues that must be considered before they are judged to be acceptable. Geometric shape of the pond is another design criteria for consideration, so that short-circuiting does not occur. That is, the wastewater should be evenly distributed over the entire pond area.

Due to government regulations and land availability in most cases, skim ponds are undesirable for future applications, especially in the United States and in Europe. As an alternative, other oil / water separators configured as vessels that may be covered, such as, API separator, parallel plate separators, or secondary oil removal units such as flotation systems (see **Section XIX-A2**) should be installed.

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SEPARATOR TYPES AND APPLICATION (Cont)

DABURT SEPARATOR

The Daburt separator is a rectangular device with an inlet broad crested weir, a plate pack, an oil skimmer, and an outlet weir (**Figure 5**). A standard unit has a nameplate capacity of 330 gpm (75 m³/hr). In addition to using gravity, the Daburt design utilizes hydraulic energy forces to promote oil and water separation. By adjusting the levels of the inlet and outlet weirs, a stationary or standing wave is generated at the broad crested inlet weir. In hydraulic terms, these conditions correspond to the critical energy, depth, and velocity of the water flowing through the inlet channel. At these conditions there is a rapid transfer in hydraulic energy from potential (depth) to kinetic (velocity). While theory governing the separation of oil under these conditions is currently not well understood, it is possible that the acceleration across the wave increases the gravity effect, potentially enhancing the efficiency of separation.

After flowing across the inlet weir, the water passes through a plate pack. The plates are spaced farther apart than in a traditional plate separator as their primary purpose is to provide a surface for microbial growth. The plate pack can be seeded with microorganisms, which may enhance oil removal by releasing or biodegrading oil that has remained attached to solids which shall be settled in the pack. Oil that floats to the surface of the settling chamber is then skimmed by either a floating disk skimmer or a slotted pipe, and the water exits via an underflow weir. Settled solids are removed via several sludge outlets.

While there are currently no installations within Exxon, there are several installations throughout the world. Exxon, however, performed a pilot test at Fife Ethylene Plant. This test, which was not seeded with microorganisms, demonstrated that the Daburt Separator was highly efficient in removing oil droplets approximately 25 microns and larger for this specific wastewater. Testing is recommended before choosing this equipment to confirm performance and maintenance requirements. For more detailed information regarding Fife's test see **Reference 12**.

PACKAGE OIL / WATER SEPARATOR

Package separators, or those separators manufactured to standard sizes typically ranging from 15 to 500 gpm (3.4 to 114 m³/hr), are presently being used in refining, chemical, marketing, production, and tanker applications. The package oil / water separators are a combination of coalescing and gravity separation plates. They are effective in high oil and solids service if careful attention is placed on providing adequate collection sumps and pumps to remove the oil and solids. The free oil removal for a given flow rate and separator is a function of the specific gravity of the oil and the water, the viscosity of the water (all of which are affected by temperature), the oil-droplet size distribution, and the overall oil concentration.

Where possible, the units should be installed above grade so that the separator plate packs can be easily removed for cleaning and to minimize potential groundwater problems. Even under ideal conditions, gravity separators cannot be designed to remove oil droplets smaller than 10 microns. The capacity of a given separator is a function of the desired oil droplet size to be removed. There is generally no turn-down limitation on package separator; feed rates lower than the design rate result in better oil removals.

Complete installation lists, including generally extensive refinery and chemical plant applications, are available from the vendors. **Table 4** is a partial list of package oil / water gravity separators vendors and Exxon installations.

At Source Pretreatment

Package gravity separators can be used to pretreat oily wastewater from individual process units, tank draw-offs, and other high oil sources prior to sewer discharge. The oils are more concentrated at these points, resulting in more efficient removal. At source recovery is more likely to yield hydrocarbons in a purer, less contaminated form, thereby retaining a product value rather than merely slop oil value. Less oil to the sewer also reduces sludge production and improves wastewater treatment plant operation.

Augment API Separator

Package separators can be used in association with or in place of API separators to achieve lower effluent free oil levels. Unlike API separators, which are sized to remove 150 µm oil droplets and larger, package units are often sized for the removal of smaller diameter globules, thereby providing a higher quality effluent. Package separators may be used in place of API separators in both grass roots and revamp situations. These units may be an efficient means of meeting newer, more stringent regulations, and may obviate the need for more extensive secondary oil removal technologies, such as flotation, coalescing, and filtration.

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SEPARATOR TYPES AND APPLICATION (Cont)

Package separators can also be used to treat skimmings from an API separator. In general, API separator skimmings tend to contain a significant amount of water. A package separator would serve to remove a significant amount of water from the skimmings, thereby reducing the load to (preventing overload) the plant sloop system. Also, the use of a package separator to treat the skimmings would allow for more frequent or continuous skimming of the API separator. This results in improved API separator performance, especially during peak hydraulic flows where accumulated oil is often discharged with the API effluent. Frequent or continuous skimming serves to lower fugitive hydrocarbon emissions from API separators, and thus may obviate the need for expensive covers. The water phase separated from package-separator treatment of API skimmings is generally recycled back to the front of the API separator or sent to downstream treatment.

Pressurized Wastewaters

If wastewater is already pressurized, e.g., produced water, separators are available to perform oil / water separation. Package separators can be fabricated as closed vessels, operated at high pressures, and with no vapor space if desired. This capability makes them superior to API separators for treating oily wastewaters generated at high pressures, such as desalter water, produced water, and onsite process water. The pressure drop in going from high pressure to an atmospheric API separator will cause emulsification, poor quality effluent, and vapor release (emissions). This emulsification would not occur to an appreciable extent using a pressurized package separator. Also, the pressurized package unit would save pumping energy if subsequent treatment steps require elevated pressures. Pressurized systems can also be used to contain volatile emissions for recovery or treatment.

CYCLONE SEPARATOR

Hydrocyclones have no moving parts, and separation is achieved by generating centrifugal forces of orders of magnitude higher than available in conventional gravity based separation equipment. The oily water enters the hydrocyclone inlet (**Figure 6**) designed to impart a high velocity swirl to the fluid, which then flows through a concentric reducing chamber, a tapered tube, and, finally, a straight tube. The fluid accelerates through the concentric reduction tapered sections of the cyclone and the bulk of the separation occurs here. The smaller, slower moving oil droplets are recovered in the straight tube section. The lighter oil droplets migrate towards the lower pressure central core where an axial flow reversal occurs resulting in the lower density oil enriched phase being removed through a small diameter orifice in the center of the inlet head. The oil depleted water stream is flung to the outside of the vortex and exits continuously from the downstream end. Typical free oil removal efficiency is 60 to 99 percent. The oil and water separation efficiency is influenced by a number of factors, the most significant of which are inlet flow rate, reject rate, oil concentration, and differential pressure.

A certain minimum flow rate is necessary to create the vortex motion and establish centrifugal separating forces which grow in intensity as the flow rate increases, thereby improving the separation efficiency. The efficiency increases to a point beyond which further increases in flow rate will cause performance deterioration. As flow rate increases, the pressure in the central core decreases, reducing the available pressure to drive the reject stream. The reject flow rate is inhibited resulting in a decline in the separation efficiency.

The reject ratio is the ratio of the flow rate of the concentrated oil stream exiting the unit to the flow rate of the discharged clean water expressed as a percentage. As the reject ratio increases, the efficiency of separation increases until a plateau level is reached. Optimum separation efficiencies are achieved at about 1 percent reject ratio (20). The reject rate, and in turn, the reject ratio is affected by the level of inlet contamination. The higher the inlet oil concentration, the greater the required reject stream.

High oil concentrations also result in high separation efficiencies. Large oil droplets move rapidly towards the central core, and at high oil concentrations, the probability of coalescence occurring to form larger oil droplets increases.

The differential pressure is also an important operating parameter. Two distinct pressure drops exist across the hydrocyclone; the pressure differential between the inlet and the outlet and between the inlet and the reject stream. The latter is always the larger of the two and is more important since it determines the hydrocyclone capacity. The reject pressure can be maintained by automatically adjusting a pressure control valve in the reject line.

The type of pump selected for handling oily water has a direct influence on system performance as do pump control and valve location. Centrifugal pumps are completely unsuitable for pumping oily water mixtures. Positive displacement pumps such as screw and gear pumps, while not entirely satisfactory, cause less droplet break-up than most.

Although Exxon refineries and chemical plants have limited experience with hydrocyclones, e.g., field test at Baytown Refinery (22), this technology has been successfully installed and operated at some offshore production locations, and mining facilities where oil concentrations were very high (over 5%).

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SEPARATOR TYPES AND APPLICATION (Cont)

CENTRIFUGES

As is the case with cyclones, centrifuges are based on the principles of centrifugal force. Relative to the wall of a container, any particle in a vortex will be accelerated outward. The vortex in the centrifuges is created by injecting the fluid tangentially into an approximately shaped chamber.

Disc centrifuges are most often used for oil / water / solid separations into distinct phases where oil content is very high (over 5%). The concentric cones, or discs, serve much as the same purpose as the plates in a plate separator. Depending on certain design features, solids come out of disc centrifuges either as a slurry or as a thicker, more paste-like substance.

Experience with this type of equipment is limited, but very good results were achieved at the Fawley Refinery where the stream to be treated was rich in solids and oil concentrations.

QUICK, ROUGH SIZING BASIS

The following Quick, Rough Sizing Basis is for the purpose of quick oil / water separator size screening only. The rules of thumb should be used with caution. For design and detailed engineering, refer to Detailed Oil / Water Separator Size Calculations section of this Design Practice.

A quick method to estimate gravity oil / water separator size (i.e., effective area) without data or details on the particular application at a given influent rate can be accomplished using Stokes chart (**Figure 7**). For example, given a temperature of 70°F and an oil / water specific gravity differential of 0.15, removal of oil droplet 60 microns and larger would require roughly 575 ft² of effective area per every 200 gpm of influent. Note that effective area refers to the horizontal projection of the separator plates, and this Figure is for only one size separator.

API SEPARATOR

The main critical parameter to size an API Separator is the flow rate. Knowing the design flow rate and using the procedure below, preliminary dimensions of an API Separator can be calculated. The minimum and the maximum flow rates for the following procedure are 1,500 gpm (340 m³/hr) and 7,000 gpm (1,600 m³/hr), respectively. For design flow rates less than 1,500 gpm (340 m³/hr), it is recommended to use the parallel plate or package oil / water separators. The rules of thumb below assume removal of oil droplet size greater than 150 microns and that there are 2 chambers.

1. Calculate the total cross sectional area for 2 chambers, in ft², by dividing the flow, in gpm, by 22:

$$\text{Area} = \text{Flow} / 22.$$

2. Assume the depth of each chamber to be 6 ft (1.8 m) for a design flow between 1,500 and 4,500 gpm (340 to 1,000 m³/hr) and 8 ft (2.4 m) for a design flow rate between 4,500 and 7,000 gpm (1,000 to 1,600 m³/hr).
3. The width, in ft, for each chamber is the area from step 1 divided by 2 times the depth:

$$\text{Width} = \text{Area} / (2 \times \text{depth})$$

4. The length, in ft, for each chamber is about 17 times the depth:

$$\text{Length} = 17 \times \text{depth}$$

PARALLEL PLATE SEPARATOR

- Two major parameters are essential to determine the size of a parallel plate separator: flow rate and Reynolds' Number. See **Eq. (15)** for derivation of the Reynolds' Number and assumed range of values for laminar flow. When these two quantities are known, the projected horizontal surface area, (A_H), in ft², can be quickly calculated by $A_H = 91.2 \times \text{Flow} / N_{Re}$, where the flow is in gpm units. The length, in ft, of the separator can be calculated by $\text{Length} = 0.01 N_{Re}$.



QUICK, ROUGH SIZING BASIS (Cont)

PACKAGE OIL / WATER SEPARATORS

The following table lists a consolidation of package oil / water separator dimensions from various vendors. These dimensions are for rough size estimates only, the vendor should be consulted for final dimensions.

Flow, gpm (m ³ /hr)	Length, ft (m)	Width, ft (m)	Height, ft (m)
50 (11.4)	9 (2.7)	3 (1.0)	7 (2.1)
100 (22.7)	9(2.7)	4 (1.2)	7 (2.1)
200 (45.4)	9 (2.7)	7 (2.1)	8 (2.4)
500 (113.5)	14 (4.3)	9 (2.7)	7 (2.1)

BASIC DESIGN CONSIDERATIONS

OIL / WATER SEPARATION THEORY

- 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 water 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 mathematical relationship for the rise rate is provided by a form of Stokes' Law:

$$V_t = 10720 \delta^2 \left(\frac{S_w - S_o}{\mu_w} \right) \quad \text{(Customary)} \quad \text{Eq. (1)}$$

$$V_t = \left(\frac{1000 \text{ g}}{18 \mu_w} \right) (\rho_w - \rho_o) \delta^2 \quad \text{(Metric)} \quad \text{Eq. (1)M}$$

where: V_t = Vertical velocity, or rise rate, of the design oil globule, ft/min (mm/sec)
 δ = Diameter of the oil globule to be removed, cm (cm)
 S_w = Specific gravity of the wastewater at the design temperature, dimensionless
 S_o = Specific gravity of the oil present in the wastewater, dimensionless
 μ_w = Absolute viscosity of wastewater at the design temperature, in cP (cP)
 g = Acceleration due to gravity = 981 cm/sec²
 ρ_w = Density of water at the design temperature, (g/cm³)
 ρ_o = Density of oil at the design temperature, (g/cm³)

There are two fundamental principles in designing and operating oil / water separators. They are:

1. 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.
2. Since the oil globules' rise rate is inversely proportional to the viscosity of the wastewater, oil globules will rise more slowly at lower temperatures.

In addition to the parameters mentioned above, changes in flow rate, salinity, oil globule size, and the method of measuring oil concentration can also affect the apparent efficiency of removal.

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BASIC DESIGN CONSIDERATIONS (Cont)

CONTAMINANTS

Caustic or other basic compounds tend to emulsify oil, adversely affecting the oil / water separator performance. Surfactants, such as non-biodegradable detergents and phosphates used in washing operations, can also cause problems in the oil / water separator. These contaminants may also add toxicity to the water discharge. For these reasons, the discharge of these materials to the separator should be avoided. An alternative is to use steam or high pressure water for washing operations.

Additionally, a "mud box" or sediment trap upstream of the separator should be installed to knock out heavy sediments, thus minimizing sludge buildup in the separator. Also, a screen should be installed to catch any floating debris before it washes into the unit.

♦ VENDOR SPECIFIC INFORMATION

Final sizing and economics are based on using the sizing methods described later in this section and vendor input. Information required by the vendor to assist in selection and sizing of separation equipment may include:

- Type of process stream and influent flow rates
- Raw water characteristics (influent oil content, oil droplet size distribution, specific gravity of water and oil phase, viscosity of the water phase, total suspended solids, dissolved solids, temperature, pH)
- Location of installation (plot space, configuration)
- Expected operating hours / day
- Process flow sheet

Selection of standard vendor design sizes may reduce cost. Often the incremental cost of choosing a slightly larger size separation unit is not high and may be prudent to allow operating flexibility.

LAYOUT

- ♦ The gravity displacement type oil / water separator in **Figure 8** shows some of the auxiliary equipment (pumps, valves, etc.) that will be required and should be taken into consideration when determining the layout of the separator. The layout of oil / water separators (**Figures 9** and **10**) strongly depends on the plot space and topographical features of the site. Ideally, the separator should be located in a place that is lower relative to the location of the areas to be served by the separator, but higher than the water discharge location from the separator. This will allow all the oily water collection lines and clean water discharge lines to gravity flow to / from the separator. When, this is not possible due to the topography of the site, the separator should be located so the oil water collection lines can gravity flow into the separator. The discharge lines from the separator can be pumped to their destination.

Installation of Archimedes' screw pumps to raise the influent into the separator may be used. 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.

Although separators can be constructed above or below ground, above ground separators are preferred from a potential groundwater contamination viewpoint. If it is a below ground separator, it may require double-walled vessel with leak detection provided between the walls of the separator depending on local regulations. Techniques against freezing, for example, insulation and heat tracing and burying the separator below the frost line, may be needed at select locations for certain wastewater streams, such as dedicated separator for ballast water. However, in general, separators are not insulated or heat traced.

When installed, the separator is typically surrounded by a layer of sand or gravel. The separator will likely experience a net positive upward buoyancy at low inventories, during a heavy rainstorm when the sand or gravel layer captures and retains a large amount of water, or if a high water table exists. Groundwater level during maintenance (cleaning) periods must also be considered. Hold down straps attached to appropriately sized "deadmen" anchors may be necessary to prevent the separator from rising out of the ground. Consult ER&E CIVIL WORKS SPECIALISTS for specific information.

MATERIALS OF CONSTRUCTION

Reinforced concrete has generally been the construction material of choice for large in ground API 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. For plate packed separators, carefully consider material selection to avoid collapse of plate separators due to elevated temperatures and aromatic content of oil.

The designer should consult EXXON'S MATERIALS SPECIALISTS before specifying construction materials for Primary Oil / Water Separators.

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SEPARATOR COVERS

Uncovered gravity-type oil / water separators in refineries produce hydrocarbon evaporation losses which vary with ambient temperature, proportion of light ends in the oil, influent oil temperature, wind effects, and design parameters particular to each location. The hydrocarbon evaporation rate from an uncovered separator in a large refinery can be tons per day and reports have indicated it can result in significant air pollution, odor problems, and loss of recoverable oil. In fact, estimates of these emissions made with various models indicate from 13 to 210 lb (6 to 95 kg) of hydrocarbon are lost per 1,000 bbl of wastewater; a covered separator, on the other hand, has been estimated to lose 2 to 8 lb. (1 to 4 kg) of hydrocarbon per 1,000 bbl of wastewater (17).

While covers usually have the primary purpose of meeting hydrocarbon emission standards, they have the added dividend of odor reduction. Odor can be a problem since human threshold values are often at the parts per billion level. Although there are usually no specific odor standards to be met, an operation producing unpleasant odors can be classified a public nuisance, resulting in legal sanctions.

COVER TYPES

As listed in **Table 5**, Exxon typically uses two main types of covers on API separators: fixed and floating. The fixed covers are a permanent concrete steel, or non-supporting foam / aluminum sandwich cover which partially covers the length of the separator. Blowoff hatches are sometimes provided to minimize damage in the event of an explosion in the vapor space. Explosion proof electrical equipment and a low-level of work activity in the area minimize the possibility of an explosion. Vapors may be collected and recovered by conventional vapor-recovery equipment or venting is provided via pressure-vacuum vents 10 to 15 ft (3 to 4.5 m) high.

There are four types of floating covers: foamed slabs, polyurethane foam encapsulated with fiberglass skin, polyethylene balls, and steel pontoons. "Foamglas", a cellular glass insulating material, uses slabs that are laid directly on the water surface without being joined. Flight scrapers are low and sweep the oil under the slabs to a slotted pipe skimmer at the end of the cover. Storm surges, however, have caused the slabs to come out of position, thereby reducing the effectiveness of the cover.

Conservaflo (or formally known as Hammondflo II) is a continuous laminar construction consisting of corrosion-resistant fiberglass skins applied over an impermeable closed cell rigid polyurethane core. A liquid and vapor type joint fastens the panels together and allows for slight differential movement. A gel coating on the top surface helps prevent deterioration by ultra-violet light.

Hollow plastic spheres (polyethylene) have also been used to cover oil separators. They range in size from 1.5 to 4.0 in. (38 to 100 mm) in diameter and resemble heavy duty ping pong balls. The ball blanket adapts itself automatically with rising and falling liquid levels, thus maintaining a seal at all times. A second layer of balls results in a marginal further improvement in evaporation reduction and completely obscures the liquid surface.

The steel pontoon cover is actually an entire automated slop oil recovery system. It features automatic pumpout of oil which has accumulated beneath the cover. The pontoon is designed to float in the oil layer; that is, above the oil / water interface. Sludge is removed semi-annually by draining one channel at a time. While the channel is empty, the pontoon rests on legs about 3 ft (1 m) above the bottom. Partial onstream cleaning is performed using hoses in the forebay to suck out some of the sludge.

The explosion hazard associated with fixed covers is minimized in floating cover installation, since the vapor space is eliminated. The advantages and disadvantages for the two main types of separator covers are listed in **Table 6**.

ADAPTABILITY OF COVERS TO EXISTING SEPARATORS

Many separators have mechanical systems which move the floating oil to a skimming device and scrape the settled sludges into bottom hoppers. These installations have either continuous flight scrapers or traveling bridges that move on rails mounted on the separator walls. A fixed roof can easily be installed over a continuous flight system. However, the traveling bridge would require construction of a low building or replacement of the bridge with a continuous flight system. Floating covers usually require modification of the conventional system. The flight scrapers may be lowered so that they function at the bottom of the floating sections, or oil may be allowed to accumulate under the cover and then be periodically pumped out.

Unfortunately, oil / water separators do not have uniform dimensions or standardized equipment. They are, in general, designed on hydrodynamic principles set forth by the American Petroleum Institute, but there the resemblance ends. Hence, it is not possible to purchase a standard off-the-shelf cover; and tailor-made units need to be designed to fit specific feed situations.

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SEPARATOR COVERS (Cont)

SEPARATOR COVER MATERIALS

A variety of materials from metals to fabrics are available for covering API separators. Needs for structural strength, chemical and fire resistance, safety and convenience can influence the choice and design of a particular material. The two major factors in determining the fixed cover materials are corrosion resistance and hydrocarbon resistance. Typical fixed cover materials used are carbon steel with coal tar epoxy coating, fiberglass, aluminum, concrete, wood planks, or silicon-cloth fabric surrounded by layers of polytetrafluoroethylene (PTFE).

Floating covers are constantly in direct contact with the oily surface, and high density polyethylene spheres, fiberglass encapsulated panels, and foamglass sheets have demonstrated good chemical resistance.

ALTERNATIVES TO COVERING SEPARATORS

The amount of oil evaporated from a separator is a function of many factors including wind speed at the oil surface, the area of oil / air interface, the time of exposure, and the oil layer's temperature. Studies indicate that a decrease in influent temperature reduces the evaporation. Other recommendations for reducing evaporation include limiting the surface area of oil and time of exposure to air by recovering more oil in the forebay and initial regions of API separators.

OIL SKIMMERS

Below are brief descriptions of oil skimmers used at Exxon affiliates. Also provided in **Table 7** are the advantages and disadvantages for each of them.

SLOTTED-PIPE SKIMMER

The slotted-pipe skimmer (**Figure 11**) is the oldest and most common type in separator channels, but may not be suitable for the preseparator flume if water level in the flume varies significantly. The slotted-pipe skimmer is recommended and is normally the preferred type for API separator channel sections. It has the capability of removing a large amount of oil that could be encountered in the event of a spill. As the name implies, this skimmer consists of a length of pipe with slots; a 60-degree slot is common. The pipe is mounted horizontally across the entire length of the channel and is supported at both ends. The pipe is rotatable and the skimmed oil and water flows into the pipe through the slots when they are rotated below the liquid surface.

Pipe diameters from 8 to 20 in. (200 to 510 mm) are used; the size depends upon the capacity required, the variation in liquid level, and the distance the skimmings must travel within the pipe. With several settling bays in parallel, the slotted-pipe skimmers are usually connected in series. 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. Normally, a 10 in. (250 mm) skim pipe should be used for runs up to 40 ft (12.2 m), and larger pipe for longer runs.

The slotted pipe can be rotated by a simple lever arrangement, chain and sprocket by a rack and pinion linkage, by worm gear, or by motor. Normally, the worm gear arrangement is recommended, since it allows more precise skimming. If a slotted-pipe skimmer is used, it should be designed to permit backward rotation, in addition to forward, to allow recovery of oil that accumulates between the skimmer and the retention baffle. The slotted-pipe skimmer is operated manually and intermittently – as required to remove accumulated oil. Automation of the skimming with a slotted-pipe has not been satisfactory and is not recommended.

ROTARY DRUM SKIMMER

The rotary drum oil skimmer (**Figure 12**) is also commonly used. It consists of a drum, mounted in a horizontal position, partially submerged below the surface of the settled oil layer. The drum is rotated by an external motor; as the drum rotates it picks up a film of oil which adheres to the drum surface. The oil film is removed by a doctor knife and directed to a trough.

The optimum rotational speed for the drum achieves a peripheral speed on the order of 0.5 to 1.5 ft/s (0.15 to 0.5 m/s). The exact proper rotational speed will depend upon the amount of oil to be removed and its viscosity. Drum diameters of 12 in. (305 mm) and 24 in. (610 mm) are available from one vendor. Submergence is on the order of 0.5 to 2 in. (13 to 50 mm). Submergence is not critical as long as the drum is in contact with the oil layer; the drum selectively collects oil even if it is also in contact with water. It is preferable, however, to keep the skimming drum out of the water phase.

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OIL SKIMMERS (Cont)

The rotary drum skimmer is not recommended if a large amount of oil is expected. When rotary drum skimmers are selected, specify that a variable speed drive and a polytetrafluoroethylene (PTFE) wiper blade are to be provided. The drum skimmer can be mounted in several ways. An "A"-frame mounted skimmer in which the frame rests directly on the separator bottom and requires no external supports is suitable for installation in existing separators. Pontoon-mounted rotary drum skimmers are applicable both where skimming is desired over many locations on the surface and where significant fluctuations in level are expected. These skimmers are available with special features; the skimmer drive, pump, and oil reservoir can be contained in the pontoon-mounted unit; ballasting provisions can be provided to adjust submergence; and two rotary drums can be provided for use where oil flows toward the unit from both directions.

HORSESHOE-TYPE FLOATING SKIMMER

The horseshoe-type floating oil skimmer (**Figure 13**) consists of a floating collecting pan buoyed up by hollow chambers on three sides. The fourth side is open, contains an oil-skimming weir, and faces in the upstream flow direction to skim on-coming oil. This skimmed oil flows out a pipe or through a hose to a sump or other reservoir. Like the slotted-pipe skimmer, the floating skimmers can remove floatable solids in addition to oil.

Floating oil skimmers can be a problem because of the difficulty in assuring that they will float at the proper level in a liquid whose density varies because of changes in waste stream composition. They are not recommended with a fixed liquid level, such as in the usual separator channel. Floating oil skimmers can be useful in the preseparator section if liquid level is expected to vary significantly in this section.

SELF-ADJUSTING, FLOATING OIL SKIMMER

The self-adjusting floating oil skimmer, also known as the Baltimore Skimmer (**Figure 14**) consists of a floating tank with a portion of the front open near the top to form the oil-skimming weir. A hollow buoyancy chamber – in effect a tank within the tank – is included to float the skimmer at the proper level. The buoyancy chamber is mounted front of center, extends across the entire width of the skimmer, and is pierced by a number of pipes to allow the skimmed oil to flow to the reservoir behind the chamber. A vertical pump-suction pipe in this aft section allows the collected oil to be withdrawn.

The device skims settled oil and collects it in the reservoir. When the collected oil is withdrawn through the pump suction line, the rear portion of the skimmer lightens, is buoyed to a higher elevation, and the skimming weir, consequently, dips lower, skimming more oil. Thus, the device is self-adjusting, skimming oil until full, then lowering the weir to skim more when the collecting pump is operated. As long as liquid is being withdrawn from the unit, it remains in the skimming position. The degree of tipping is proportional to the rate of liquid removal.

Like the horseshoe-type floating skimmer, the self-adjusting, floating oil skimmer may present difficulty in assuring that it will float at the proper level in a liquid of variable density caused by changes in waste stream composition. In addition, floating scum, solids, etc., would tend to enter this skimmer but not be removed through the submerged pump suction line; so plugging – partial or complete – is likely. It may, however, be a useful oil skimmer with a varying liquid level, and in some instances might be appropriate in a preseparator section. It can handle large oil spills. Other floating oil skimmers have been devised for marine oil spills; some of these have been considered for preseparator channels, but are not discussed here.

DISC SKIMMER

The disc skimmer (**Figure 15**) consists of one or more large discs which are set on a frame which may be mounted directly on a tank or on floats. The skimmer can be adjusted at varying angles to the horizontal so that a greater surface area of the disc is in contact with the surface oil.

The skimmer normally is driven by a geared reversible air motor. This allows the disc to be run at low speeds where minimal water content is required and also it may be reversed to clear it from rubbish if necessary. Air power is favored for simplicity of operation, low wear and tear, easy maintenance and safety. Electrical motors may be a potential fire / explosion hazard. If an alternative to air is necessary, it is recommended to use a hydraulic motor.

The disc may be made from a variety of materials, but experience with certain plastics appear to have oleophilic properties which have shown an increase in the take-off when compared with stainless steel. Burt Environmental Systems produces this type of skimmer and has been field tested at Fife Ethylene Plant and overall results were very good. It is, however, strongly recommended to check the metallurgy of the skimmer to make sure an appropriate material is used for the wastewater involved.

Other examples of disc skimmers are DISCOIL and KEBAB which operate based on the adhesion of the floating oil to the appropriately treated surfaces of the discs. The discs are perpendicularly placed, partially immersed with respect to the surface of the liquid, and maintained in rotation with respect to their horizontal axis. The floating product extracted from the water is separated from the discs by means of special scraper blades, which convey it towards an accumulation tank from which the product is then transferred to a preselected place for storage. Trecate and Augusta refineries installed DISCOIL in their systems and it has performed well on light oils, as well as on the dirty rainwater retention basin.

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API SEPARATORS CONSTRUCTION DETAILS

The API separator consists of two sections: the inlet section and the separator channels. The dividing point is the gateways for channel shutoff. The inlet section generally includes a preseparator flume, trash rack, oil skimmer, retention baffle, and forebay. The separation section usually includes gateways, distribution devices, oil and sludge moving equipment, oil skimming equipment, oil retention baffle, sludge collection and removal facilities, and an effluent weir. The various components of both sections of API separator are shown in **Figures 9 and 10**.

INLET SECTION

Preseparator Flume – The preseparator flume is the transition between the end of the inlet sewer and the separator forebay. It serves two functions: reduction of flow velocity and collection of floating oil. In flat terrain refineries, most of the oil flowing to a separator usually can – and should – be recovered in the preseparator flume.

The transition between the sewer outlet and the preseparator section is designed to accomplish velocity reduction with a minimum of turbulence.

The preseparator section is designed to reduce the horizontal flow velocity to about 10 to 20 ft/min. (3 to 6 m/min), with 1 to 2 minutes average retention time.

The transition and separator sections of the preseparator flume may be required to be covered to reduce evaporation loss as mandated by government regulation. When this is the case, the vapor space should be enclosed by a barrier or wall at the downstream end of the cover.

The preseparator section contains three pieces of equipment: a trash rack or bar screen, an oil skimmer, and an oil-retention baffle.

Trash Rack – Trash racks or bar screens are provided to remove sticks, rags, stones and other debris. The trash rack consists of a series of bars or rods. Bars 3/8 in. by 2 in. (9.5 mm by 50 mm) with clear openings of 3/4 to 1 in. (19 to 25 mm) are typical.

Trash racks can be cleaned manually or mechanically. Manually-cleaned racks are inclined 45 to 60° from the horizontal, depending upon the depth of the flume and space availability. Mechanically cleaned bar screens can be mounted vertically, but generally are sloped.

A pan or trough is provided at the top of the trash rack to receive the refuse when the trash rack is cleaned. The refuse pan should be perforated to allow liquid drainage back into the flume.

Oil Skimmer – The next piece of equipment downstream of the trash rack is usually an oil skimmer. This oil skimmer is included to collect that part of the influent oil that is already on top as the stream enters. An oil skimmer and oil retention baffle should normally be specified for the effluent end of the preseparator flume.

Many types of oil skimmers can be used in oil separators. Slotted-pipe, rotary drum, horseshoe-type floating skimmer, self-adjusting floating skimmer, and disc skimmer have all been used. A sixth type, the rotary belt skimmer, is not commonly used in API separators. The types of skimmers that have been used include not only those that can be used in the preseparator flume, but also skimmers for the forebay and separator channels. See previous section for oil skimmer description and applications.

Oil Retention Baffle – An oil retention baffle should be located not more than 12 in. (305 mm) downstream of the oil skimmer. The oil retention baffle should be high enough to prevent oil from flowing or splashing over it. Submergence of this baffle should not exceed 18 in. (460 mm).

Separator Forebay – After flowing past the trash rack and under the oil skimmer and oil retention baffle, the water from the preseparator flume discharges into the separator forebay. This part of the separator acts as a header and distributes the influent to the separator channels. If the preseparator flume is oriented at a right angle to the separator channels, the separator forebay accomplishes the change in the direction of flow. The forebay part of an API separator can be seen in **Figures 9 and 10**.

Sludge deposition is even more likely in the forebay than in the preseparator flume. Means for sludge removal should be provided, particularly if the flow diffusion device at the inlet to the separation section is of the reaction jet type.

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.



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API SEPARATORS CONSTRUCTION DETAILS (Cont)

SEPARATION CHANNELS SECTION

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.

Gateways – Each channel is provided with one or more gateways at its inlet to allow shutting off the flow to the channel when desired. Permanently installed gates may be provided, but it is also acceptable to merely provide slots in the gateway piers such that metal sheets, wooden boards, or possibly plastic sheets of the proper size can be dropped into the slots when required to stop the flow. The gate frame and slots should be of suitable corrosion-resistant and erosion-resistant materials.

Velocity Head Diffusion Devices – Immediately downstream of the inlet gateway is a diffusion device to distribute the flow equally over the cross-sectional area of the channel and to reduce flow turbulence. Two types of diffusion devices are available: vertical slot baffles and reaction jets. Only the reaction jet type should be used.

1. **Vertical-Slot Baffle** – A vertical slot baffle is formed from vertical posts. This type of distributor has suffered from severe fouling and is not recommended.
2. **Reaction Jet Inlet** – A reaction jet consists of a tube or orifice and a dished target baffle (**Figure 16**). 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 ft/s (0.15 m/s). The tubes project into the separator section from the inlet.

Following **Figure 16**, the reaction-jet inlets should be installed based on the following criteria:

- The baffle's radius of curvature (R), in inches, is equal to the tube or orifice diameter (D) in inches.
- A diameter is selected such that it is sufficient to maintain a design flow velocity of 3 ft/s (0.9 m/s) in the tube or orifice.
- The baffle diameter (D + 1) is 1 in. (25 mm) larger than the tube or orifice diameter.
- Minimum tube diameter is 3 in. (75 mm).
- The baffle is located downstream of the tube or orifice at a distance equivalent to 0.25 to 0.6 of the tube diameter. A proper distance is required to avoid clogging.
- A hole may be provided in the center of the baffle to improve distribution. The area of this hole should be 6% of the plane area of the baffle.
- 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 lowest point on the floor of the forebay should be at the midpoint of the separator channel).
- 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.

Reaction jets have a number of advantages:

- They are less subject to clogging than vertical slot baffles.
- They provide good distribution over a wide range of flow rates.
- They are cheaper than vertical slot baffles.
- They can be shut off easily, since they are relatively small orifices in solid barriers, thus obviating gates or dams for interrupting the flow for maintenance.
- They may result in less oil in the channel effluent than with vertical slot baffles.

Oil and Sludge-Moving Devices – The separator channels contain a mechanical device to move the separated oil and the sludge to the collecting area. The floating oil is moved to the downstream end of the separator; the settled sludge is moved to the upstream end. Two oil and sludge moving devices are available: the traveling bridge or span type and the flight scraper or chain type. Of the two, the traveling bridge (span) type, while the more expensive, has several advantages and is generally preferred. A description of each and certain important design considerations are given below.

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- Traveling Bridge or Span Type (Figure 17)**– The traveling bridge or span oil / sludge moving device consists of one or two blades extending across the width of the channel hung from a beam or truss spanning the channel. The span rests on wheels in a carriage arrangement; the wheels rise on rails at the sides of the channel and travel the length of the basin. The wheels are chain-driven; the rails are located on top of the channel walls.

The blades are adjusted to sequentially skim oil on the downstream travel and scrape sludge on the upstream flight. The one-blade arrangement accomplishes this by adjusting the height of the blade to either oil level or channel bottom using hoist or cam mechanism. The blade pivots on the underside of the bridge as height is changed. The two-blade arrangement achieves the sequential movement of material by either of two means. During oil movement, the sludge blade can be moved out of the channel or it can be feathered parallel to the channel bottom. At the end of the downstream run, the oil moving blade is raised out of the water and the sludge-moving blade is properly positioned to move sludge upstream on the return trip.

Surface travel is typically on the order of 2 ft/min. (0.6 m/min.); bottom travel is on the order of 1 ft/min. (0.3 m/min.).

This device can span and operate in one or several channels. Operation can be manual or continuous; but is, preferably, automatic and actuated intermittently by a cycle timer.

The traveling bridge type oil / sludge moving device offers the following advantages over the chain type:

- The parts requiring lubrication are located above the water.
- It allows different travel speeds on the forward and reverse runs.

Undesirable features of the traveling bridge device are:

- More expensive than other types.
- Requires a movable power cable; usually either a cable reel or a festoon system using a cable looped from a supporting wire.
- Complicates covering the channels.

A design specification for a traveling bridge type device should include the following features:

- Provide full width skimming.
- Provide totally enclosed, explosion-proof, weather-proof drivers.
- Provide overload protection.
- The current collector (third rail) type of power supply is **not** acceptable.
- Provide facilities for leveling the blades.
- Provide means to raise blades out of the water for maintenance.

- Flight Scraper or Chain Type (Figure 18)** – The flight scraper type of oil and sludge moving device consists of two parallel, endless chains, one at each side of the channel, with flights connected to the chains across the channel width. The assembly is moved at a flight speed on the order of 1 to 2 ft/min (0.3 to 0.6 m/min) by motor-driven sprockets. As the flights at the oil layer travel downstream, separated oil is moved toward the oil skimmer; on the return trip the flights push the settled sludge on the bottom of the channel toward the sludge-collecting hoppers or trough at the inlet end.

Flights can be spaced uniformly along the entire length of the chain, but flights on only one-half of the chain length are usually sufficient and are preferred because the smaller the number of flights, the less the turbulence. The flights should span the entire width of the channel. Typically, flights are 8 in. (205 mm) high and spaced on 10–ft (3 m) centers.

Only one oil / sludge moving device per channel should be installed. Power requirements are low; a driver motor size on the order of 1/2 HP is normally provided. The motor and speed reducer assembly may be mounted directly on the concrete. Each oil / sludge moving device in a parallel channel installation should have its own drive unit operating independently of the others. Normally, these devices do not operate continuously, but only as accumulations warrant. Operation can be either automatic (timer) or manual.

Advantages of the flight scraper type oil / sludge movers are:

- Low initial cost.
- Easier to accommodate a channel cover if desired for air pollution control or reduce evaporation losses.

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The disadvantages of this device are:

- Requires underwater bearings.
- Sludge can accumulate on chain and sprockets.
- Moves at the same speed on the top and the bottom of the separator.
- Chain sag can redistribute oil beneath the water surface.

A design specification for flight scraper type oil / sludge moving devices should include the following features:

- Full width skimming.
- Totally enclosed, explosion-proof, weather-proof drivers.
- Overload protection on driving sprocket.
- Provide shaft aligning facilities.
- Provide flight leveling facilities.
- Provide chain guards for personnel protection on chains above grade or near stairs, ladders, platforms, accessways, etc.
- Provide chain tighteners.
- Collection chain to have at least 30,000 pounds (133.4 kN) ultimate strength.
- At least 5 links of each chain strand to be pinned and cottered.
- Two attachments in each chain strand to be of the pivoted type, for positive cleaning of lower channel corners.
- Provide angle tracks for supporting surface run of sludge collectors.
- Provide rails flush with tank bottom for wear surfaces.
- Use corrosion resistant anchor bolts.
- Flights to be spaced at 10-foot (3 m) intervals.
- Flights to be 8 in. (205 mm) high.
- If wooden flights are used, they are to be 3 in. x 8 in. (75 mm x 205 mm) redwood or treated wood, and provided with wearing shoes to contact bottom rails.
- Provide squeegees of spark-proof construction on two flights for positive cleaning of the tank wall at the water surface and at the tank bottom.

Oil-Skimming Device – An oil-skimming device is provided at the end of each separator channel. Oil-skimming devices have been previously described under Oil Skimmers. The same devices can be used in the separator channels. A slotted-pipe oil skimmer is recommended for the separator channels. If minimum collection is required, a disc skimmer is recommended.

Oil Retention Baffle – An oil retention baffle is provided just downstream of the oil skimming device, spaced not more than 12 in. (305 mm) downstream of the skimming device. The baffle is installed with a maximum submergence of 55% of water depth; it should extend to the top of the channel.

Sludge Collection and Removal – The sludge moved by the pushing device to the inlet end must be collected and removed. The sludge may be considered hazardous depending on site specific environmental regulations. Consequently, the sludge should be disposed accordingly.

Sludge can be collected in either of two types of containers: sludge hoppers or a sludge trough. Sludge can be removed by three means: underdraining using hydrostatic pressure, siphon pipe using hydrostatic pressure, and underdrain to a sludge pump.

1. **Sludge Collection** – The preferred method of collecting sludge is the hopper (**Figure 19**). The hoppers consist of inverted pyramids with sides sloped at least 45°. With an underdraw system, each hopper contains an exit pipe at the apex; the exits discharge into a sludge withdrawal pipe. With a siphon system, no bottom exit is required.

The use of the V-bottom trough, an alternate sludge collecting device, requires a flowable sludge. The V-bottom trough is located on the downstream side of the inlet wall and is built in the channel across its total width. The bottom of the trough starts at a depth of 12 to 30 in. (305 to 760 mm) and slopes downward to a collecting sump at the other end of the channel. The sides of the "V" should slope at least 45°.

Although not usually required, other sludge collecting devices are available. For example, with a hard-to-move sludge, screw conveyors or transverse chain flights can be used to move the sludge toward the collecting sump for pump-out.

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2. **Sludge Removal** – Sludge can be removed by siphoning, gravity flow through an underdrain or by pumping. Siphoning and gravity flow through an underdrain rely upon the hydrostatic head of the water in the channel to pressure out the sludge, and can only be employed when the sludge does not require discharge to an elevation above water level. Topography may dictate otherwise.

Sludge pumping can elevate the sludge above water level. Pump suction can be from a sump or through a hopper underdraw system.

Underdraw systems, both gravity and pumped, are equipped with shut-off plug-type valves in the bottom outlet of every hopper. The valves are opened from a position at the top of the separators by lifting the plug. The plug lifting action can be manual, by a step-on pedal, or by a screw system. Automatic plug valves actuated by a timer can also be utilized.

Sludge should be removed from one hopper at a time. The frequency of sludge removal will depend upon the amount collected. Pumping sludge from the collecting hoppers once per day is usually appropriate.

Another alternative to the sludge removal mechanisms 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.

- ▶ **Effluent Weir** – An effluent weir wall is located downstream of the oil retention baffle, spaced not more than 2 ft (0.6 m) downstream. The weir wall extends from the channel floor to a height equal to the water depth less the height of the water over the weir at normal flow rate.

A sharp-crested or notched 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. Provision should be made to prevent leakage between the weir plate and the concrete weir wall. The head over an unnotched weir (the more common type) can be calculated from the following equation which is a rearrangement of the Francis formula with converted units.

$$H = 0.351 \left(\frac{Q}{l} \right)^{2/3} \quad \text{(Customary)} \quad \text{Eq. (2)}$$

$$H = 0.283 \left(\frac{Q}{l} \right)^{2/3} \quad \text{(Metric)} \quad \text{Eq. (2)M}$$

where: H = Head over the weir, in. (cm)
Q = Discharge rate, ft³/min. (m³/d)
l = Length of weir, ft (m)

The effluent flows over the weir into a channel and flows by gravity or is pumped to the sewer. Turbulence created during the free fall over the weir into the outfall channel may create an oily aerosol and result in a pollution. This can be minimized by modifying the downstream face of the effluent weir wall to resemble a spillway.

Skimmed Oil Sump – The skimmed oil from the main separator channels, as well as from the preseparator, generally flows by gravity to a common sump. The sump provides a reservoir for the pumpout pump, and in addition can be used to allow water to separate from the oil. The general arrangement for a skimmed oil sump designed to effect separation of the water from the skimmed oil, and separate pumpout of the two phases, is shown in **Figure 20**.

The sump is equipped with two vertical centrifugal pumps, one to return separated water to the API separator inlet and the other to transfer the skimmed oil to slop-oil tankage. (An alternative arrangement, requiring more attention and manual operation is a single pump, alternate discharge routes with block valves, and a funnel at the discharge to the separator inlet to allow visual inspection for completion of separated water return). Level controls of the float, electric probe, or air differential pressure type actuate the pumps at high level and switch them off at low level (an alternate is manual actuation with automatic shutoff only).

Frequently the sump is not designed to separate water from the skimmed oil, and the entire skimmed stream is pumped from the sump to a slop tank where the separation is done.