A NEW TYPE OF HIGH EFFICIENCY OIL- WATER SEPARATOR FOR BETTER WATER QUALITY MANAGEMENT

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PACFIC NORTHWEST POLLUTION CONTROL ASSOCIATION
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ABSTRACT Environmental regulation of oil in water discharges is becoming increasingly more stringent. Many localities now require oil content of water discharges to be limited to less than 1 0 ppm. Various types of systems are available to remove oil from waste or storm water streams. The systems available are discussed, including benefits and drawbacks of each. The design and advantages of a new high efficiency oil water separator system are described. Overall oil-water separator system design is discussed and recommendations for ensuring system efficiency, regulatory compliance, reliability, and effective operations are presented.

Keywords: Oil-Water Separator, wastewater, stormwater

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BACKGROUND AND INTRODUCTION

For centuries, humanity has known that oil and water do not mix - at least not very well. What ancient man did not realize is that oil and water will mix under certain conditions, forming emulsions that can be very difficult to separate. Mixtures of oil and water in aquatic environments become more troublesome each year because of increasing volumes of oil dumped into rivers and the ocean. Each year it becomes more difficult to protect the environment from the encroachment of mankind.

HISTORY OF OIL IN WATER

Natural oil has been seeping into water for centuries. The Greek historian Herodotus reported petroleum and tar as early as 450 B.C. (Nelson, 1969). Laws (1981) noted that natural gas from the Kirkuk oil field in Iraq has been burning since biblical days, and that reports of oil seeps in the ocean off Coal Oil Point in California were noted as early as 1629. Until the advent of the automobile as a major mode of transportation, petroleum was of little use except as a lubricant and a replacement for whale oil in oil lamps. Today, many freshwater systems are polluted with oil, and the largest single source of oil discharge to the oceans is river runoff (Laws, 1981). In a National Academy of Sciences study, it was estimated that in 1970 total discharges to the marine environment were about six million (6,000,000) per year, of which 10% came from river runoff. In order to protect the marine environment and their precious resource of fish and plants, it is therefore necessary to protect the rivers and streams that run into the oceans.

WHAT IS OIL AND WHY IS IT A PROBLEM?

Crude oil is a variety of complex hydrocarbon substances composed of thousands of different kinds of molecules. Crude oil from different fields can have varying properties. Some light crudes have specific gravities as low as 0.85, while others have specific gravities up to 1.15. Crudes may contain mostly alkanes, alkenes, aromatic compounds, or asphaltic compounds. Alkanes and alkenes are often lumped together under the term aliphatics. Most contain mixtures of one or more of these types. Refined products have an even greater range of properties than crude oils because many have molecular structures not commonly found in nature. Both natural and refined products may also contain sulfur or nitrogen compounds that change their characteristics. Small concentrations of metals may also be present in crude oil, i.e. iron, nickel, arsenic, and vanadium (Nelson, 1969). Most of these metals are removed in the early stages of the refining process because their presence in the process can cause corrosion or poison refining catalysts.

Gasolines are composed mainly of aliphatic compounds and aromatic compounds. Oxygenates such as methyltertiarybutyl ether (MTBE) in percentages up to fifteen percent (i 5%) (Nelson, 1969). Aliphatics also predominate in kerosene, diesel fuel, and jet fuel. Even though leaded gasoline is being phased out under current EPA regulations (Findley and Farber, 1992), it is still available in some localities, and is toxic because of the lead compounds present. In addition to the petroleum related compounds, vegetable oils and animal fats are also considered to be oils (Romano, 1990). Since these are generally biodegradable, they are usually not considered a problem unless they are present in very large quantities. For purposes of this investigation, the term “oil” will be taken to mean petroleum-based hydrocarbons. Toxic effects of oil fall into two categories (Laws, 1981):

1) Effects due to smothering or coating of an animal or plant with the oil. These coating effects are most often associated with crude oil and primarily impact on sea birds and some sea animals such as sea otters, seals, etc. Coating effects are most noticeable when large amounts of free oil are present as in an oil spill. Coating effects are not usually found when only parts per million (ppm) are present as is the case in an industrial plant effluent.
2) Disruption of the animal or plant's metabolism due to the ingestion of the oil and incorporation of the oil into the organism's fatty tissues. Generally, toxic compounds are not water soluble and are oil soluble, so thus tend to accumulate in body fat. This accumulation of toxic compounds in the fatty tissues is damaging to an animal or human being. Toxic effects can be seen in oil spill cases, and also as effects of industrial effluent and urban runoff pollution. It is now thought that aromatic hydrocarbons are the most toxic, followed by cycloalkanes, olefins (alkenes), and lastly alkanes.

Benzene, one of the aromatic components of gasoline, is known to be carcinogenic. Some other gasoline components, notably toluene, ethyl benzene, and xylenes are also aromatic compounds. Some other hydrocarbon based chemicals, notably Polychlorinated Biphenyls (PCBS) are aromatics and also known to be carcinogenic. Generally, hydrocarbons are not soluble in water. Some hydrocarbons do have a small solubility in water and unfortunately the lighter, more water soluble hydrocarbons have a tendency to be more toxic than the heavier, less soluble ones (Laws, 1981).

THE POTENTIAL SOURCES OF OIL IN WATER AND THEIR RELATIVE IMPORTANCE

Many possible sources of oil in water exist. Ignoring natural seeps, these can be divided into five general categories (adapted from Laws, 1981):

1) Industrial continuous sources
2) Industrial spills
3) Oil spills
4) Urban runoff
5) Domestic/Miscellaneous sources

Industrial continuous sources are the easiest to deal with as they are generally "point sources", have generally constant flow and constant oil content. These sources, such as refinery water outfalls, are often large sources of hydrocarbons. Point sources can be dealt with either by installation of oil-water separators or by elimination of individual sources of oil within the refinery or other industrial plant. From a regulatory standpoint, "oil and grease" content of these sources are regulated under the NPDES program. Industrial spills are likewise a problem that is relatively easy to deal with because it is possible to predict where spills may originate and to take preventative measures to capture spills before they enter the environment.

Spills from oil tanker accidents such as the Exxon Valdez disaster have the potential of being very damaging and various plans have been advanced to safeguard against such problems. Spills from oil wells, especially onshore ones, have become infrequent due to increased efforts to alleviate this problem (Green and Trett, 1989).

Urban runoff water is primarily caused by stormwater from streets and highways. Hydrocarbons in this water include primarily gasoline fractions, diesel fuel, and automotive and truck crankcase oil leaks. Of these, crankcase lubricating oil predominates in runoff water (Romano, 1990).

Domestic/Miscellaneous sources are much harder to eliminate as they are so diverse. These sources of oil include (Romano, 1990, Stenstrom, et al., 1984, Green and Trett, 1989):

1) Non-highway leaks from vehicles, especially crankcase oil.
2) Illicit dumping of used motor oil into storm drains.
3) Discharges from motorboat exhaust and leaks from boats.
4) Industrial wash down - machine wash down

LAWS AND REGULATIONS

Oil in water discharges from industrial and other facilities are governed by a variety of federal, state and local laws. Included are the Clean Water Act (CWA) and its amendments, the Oil Pollution Act of 1990, the Coastal Zone Management Act and others (Findley and Farber, 1992).

Most hydrocarbon wastes are not covered by the Resource Conservation and Recovery Act of 1976 and its amendments (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) also known as the Superfund Act (Findley and Farber, 1992). These wastes, produced by the extraction, transportation, refining, or processing of oil and natural gas, are specifically exempted from being regulated as "hazardous wastes" under any other laws.

The basic law covering discharges is the Clean Water Act. It was originally enacted as the Federal Water Pollution Control Act of 1972, but was amended extensively in 1977. The 1977 amendments, in conjunction with the earlier legislation, became known as the Clean Water Act. Under the terms of this Act, amended Section 402 created the National Pollutant Discharge Elimination System (NPDES) permit system. Permits for point sources under this system are granted by the Environmental Protection Agency (EPA) or by states with EPA approved programs. After enactment of this law, any discharges other than those covered by the permit are illegal. Although the Clean Water Act was enacted primarily to control discharges from Publicly Owned Treatment Works (POTW's) and toxic discharges from industrial plants, it also controls discharges of petroleum and other hydrocarbons into the waters of the United States.

The courts have ruled that the EPA has the power to set effluent limitations by classes of facilities (E.I. DuPont de Nemours & Co. v. Train, 430 U.S. 11 2 (1977)) and that the EPA does not have to consider the quality of the receiving waters in setting effluent limitations (Weyerhaeuser Co. v. Costle, 590 F-2d 1 01 1 (D.C. Circuit.1 978)) (Findley and Farber, 1992).

Most states and localities require discharges to contain 15 ppm or less oil and grease, based on a 24 hour composite sample. Oil and grease may include petroleum hydrocarbons as well as animal and vegetable oils. Some localities have established lower discharge limits. King County, Washington, which includes the Seattle area, requires discharges to be less than 1 0 ppm. (Romano, 1990).

Also important are the new stormwater management rules published by the EPA in 1990 (NPDES Permit Application Regulations for Storm Water Discharges; Final Rule, 1990). The reasoning behind stringent regulation of stormwater is included in the "National Water Quality Inventory, 1988 Report to Congress", as discussed in the Federal Register, November 16, 1990. This report concludes that "pollution from diffuse sources, such as runoff from agricultural, urban areas, construction sites, land disposal, and resource extraction is cited by the States as the leading cause of water quality impairment." These sources appear to gain in importance as discharges of industrial process wastewaters and municipal sewage plants come under increased control. A study conducted by the Huron River Pollution Abatement Program (Federal Register, November 16, 1990) detected illicit discharges to storm sewers at a rate of 60% (of the number of businesses surveyed) in businesses related to auto- mobiles such as auto dealerships, service stations and body shops. This study noted that most of these discharges to the sewer had been legal when installed.

Stormwater discharges were covered under the CWA but not required to have permits under the NPDES system until the final rules were published in the Federal Register, November 16, 1990. "Stormwater discharges" refer to discharges consisting entirely of rainwater runoff, snowmelt runoff, or surface runoff and drainage. Waters that do not meet this definition are not covered by these regulations. The new rules specify that facilities with stormwater discharges from "areas containing raw materials, intermediate products, finished products, by-product, or waste product located on site" will require a NPDES permit. Several categories of facility are specifically exempt from these regulations, notably stormwater runoff from mining operations, oil and gas exploration, production, processing, or treatment operations, and parking lots whose rainwater sewers are not interconnected with manufacturing facility sewers.

A study has shown (Hunter, et al, 1979), that runoff water from highways can contain an order of magnitude more hydrocarbons than runoff from other urban areas. Most of the hydrocarbons in runoff are associated with particulate matter. This indicates that separators designed to deal with stormwater should also be designed to handle the associated solids, and that the design of the separator should be based on the composite specific gravity of the oily solids. Hunter, et al. indicated that roughly 30% of the hydrocarbons in runoff are aromatic while the balance are aliphatic.

SYSTEMS AVAILABLE FOR REMOVING OIL FROM WATER

Systems for removing oil from water range from very simple holding ponds with or without skimming arrangements to very elaborate membrane technology-based systems. For most applications in removing oil, the simplest systems are often inadequate (although often used) and the most complicated are either too expensive or too maintenance-intensive. Most of the following discussion, therefore, will concentrate on methods of separation intended to meet regulatory requirements with minimum cost and maintenance.

Gravity Separation

The simplest possible separator is an empty chamber with enough volume to contain spills. A typical spill control separator is shown in Figure 1 (Romano, 1990). A spill control separator is too small to intercept small droplets and is only suitable for intercepting spills of oil or grease. Spill control separators are only effective if any accumulated oil is removed regularly. If the oil is not removed regularly, a storm may flush the accumulated oil out of the separator into the downstream sewer (Romano, 1990). The American Petroleum Institute (API) provides design criteria for oil-water separators. A design method is provided in the API Manual on Disposal of Refinery Wastes, Chapters 5 and 6-Oil-Water Separator Process Design and Construction Details (API publication 1630, 1979). API separators are gravity type separators similar to spill control separators, but are generally larger, more sophisticated, more effective, and are usually equipped with oil removal facilities. API separators are extensively used in oil refineries and chemical processing facilities where waters containing relatively large amounts of oil are present and need to be processed to meet the requirements of NPDES permits. A diagram of a typical API separator is shown in Figure 2 (Adapted from API Publication 421, 1990).

The API separator has successfully been used in refineries for many years. It is much more effective than simple holding ponds or spill control separators. Advantages of the spill control separator and API separator are simplicity of design, low cost, low maintenance, and resistance to plugging with solids. The primary disadvantage of these simple gravity separators is the poor quality of separation that they provide.

Enhanced Gravity Separation

Enhanced gravity separators provide better separation quality than is possible with simple gravity separators while maintaining the low capital and maintenance cost benefits of the simple systems. In many ways, the enhanced gravity separators substitute sophisticated design for the settling time provided in pure gravity separators. These enhanced gravity separation systems have some similarity to API separators, but include additional internal features that enhance the separation of oil and water. These internal features are basically a substitute for the additional residence time provided by the API separators.

Designs that have successfully been used are:

1) Coalescing plate separators
    a. Inclined plate separators
    b. Horizontal Sinusoidal (flat corrugated) plate separators
    c. Multiple angle separators
1) Coalescing tube separators
2) Packing type separators

Coalescing plate separators:

Inclined plate separators

Inclined plate separators have been used successfully for many years. (Romano, 1990). These systems are usually made in large modules constructed of fiberglass corrugated plates packaged in steel or stainless steel frames. The oil droplets entering the system rise until they reach the plate above, then migrate along the plate until they reach the surface. Plates in this type system are often 3/4" apart, but may be as much as 4" apart (Romano, 1990).

Advantages of this system include improved efficiency at removing both solids and oil (over API type separators) and resistance to plugging with solids (Romano, 1990). Figure 3 shows a schematic of a typical inclined plate separator (Romano, 1990).

Flat Corrugated (Horizontal Sinusoidal) Plate Separators

Flat corrugated plate separators often use horizontal oleophilic polypropylene plates stacked one on top of another in vertical stacks and fastened into packs with rods or wires. Figure 4 illustrates a drawing of a typical flat corrugated plate separator system.

The system uses a combination of laminar flow coalescence and oleophilic attraction. Slowing the flow of water to low velocities where laminar flow regimes exist minimizes turbulence. Turbulence causes mixing of the oil and water and reduces oil droplet sizes. Stokes's law states that larger droplets will rise faster and thus separate better. The oleophilic nature of the plates allows the oil droplets to attach and encourages them to coalesce into larger ones which will rise faster.

These plates provide better separation than could be arrived at without plates. The advantages of this system are that the plate packs are modular and relatively small in size compared to the inclined plate modules. Corrugated plates in this type system are spaced a nominal 0.25" to 0.5" apart. Because the plates are corrugated, rise distances of droplets in the vertical direction are greater than the perpendicular distance between plates. The oil droplets must rise approximately 0.4" for the nominal 0.25" spacing and 0.7" for the nominal 0.5" spacing. Because spacing varies slightly due to variations in plate molding and assembly the spacings are referred to as nominal 0.25" and 0.511 while varying somewhat from these dimensions. Figure 5 provides a detail of part of a separator pack and includes a graphic depiction of rise distances. Because the vertical rise distance to be covered is less than for the inclined plate systems, the same size particle is separated in less time. Conversely, the same amount of space time provided within the plate area causes effective separation of smaller size particles.

Disadvantages of this system are possible plugging of the plate packs by solids and possible damage to the plates by solvents that could attack the polypropylene plates. Plates placed vertically help to alleviate plugging by solids.

Multiple Angle Plate Separators

Multiple angle plate separators were developed to take advantage of the virtues of the horizontal sinusoidal separator plates while eliminating many of the disadvantages. A drawing of a multiple angle separator is contained in Figure 6. The plates are corrugated in both directions, making a sort of "egg-carton" shape. Spacers are built into the plates for two spacings (nominal 0.25" and 0.5", or 8 mm and 16 mm). Figure 7 shows a drawing of a multiple angle plate pack assembly.

Advantages of the multiple-angle system are:

1) The plates are designed to shed solids to the bottom of the separator, avoiding plugging and directing the solids to a solids collection area. In inclined plate systems, solids must slide down the entire length of the plates whereas in the multiple angle systems the solids only have to slide a few inches before encountering one of a multitude of solids removal holes. The solids drop directly to the bottom of the separator.
2) The supports that form part of the package also provide a space under the plates that constitutes a solids collection area. In some designs separate supports are provided for this purpose.
3) The double corrugations provide surfaces that slope at a forty-five (45) degree angle in all directions so that coalesced oil can migrate upward.
4) The holes in the plates that constitute the oil rise paths and solids removal paths also provide convenient orifices for insertion of cleaning wands. Other types of

pack systems are not provided with such holes and are more difficult to clean when plugged with solids.

Testing of the plates was conducted in a steel tank intended for aboveground installation. This unit is referred to as a HEROWS (High Efficiency Round Oil-Water Separator). It was designed specifically to take advantage of the virtues of the multiple angle plates which may be used in either aboveground units in below-grade concrete vaults or other type tanks.

The advantages of the aboveground units are that they are factory fabricated and require a minimum of field installation time. Most large units are designed utilizing plates installed in in-ground vaults. The primary advantages of vault installations are that the cost per unit flow is minimized and the below-grade installation is both convenient for gravity flow applications and does not waste valuable plant area.

Coalescing tube separators:

Coalescing tube separators utilizing perforated plastic tubes for separation have been used for separation of oil and water. The advantages of the use of this type separator are low cost and enhanced separation due to the oleophilic nature of the packing. The disadvantage is that the oil separation from the tubes is more or less random and therefore not optimized. Figure 8 shows a drawing of a coalescing tube separator.

Packing type separators:

One other system that can be used for coalescence is routing the emulsion through a bed of packing such as excelsior (Love, 1948). Experimental data indicates that most of the coalescence occurs in the first few inches of excelsior. This type of coalescer is often used in conjunction with gravity separation or inclined plate separation as a polishing stage. Similar packs have been made of other materials, including stainless steel and polypropylene. Systems of this type can be efficient, but the tightly packed coalescing media can experience plugging problems. Coalescing media of this type is often used as a second stage after a plate type first stage of separation. In this type application, it is common to use plastic woven mesh of the type often used as demister pads in distillation columns. Figure 9 is an illustration of this type separator.

Exotic systems:

Reverse osmosis membranes and other exotic means of removing oil from water are sometimes used. These units are usually too expensive to be used for wastewater treatment. Dissolved air flotation is also used.

Another expensive but effective means of removing residual oil in water is the use of activated carbon. Carbon is sometimes used as a polishing step, but can be prohibitively expensive if the first stages are not effective.

Applications of the Different Systems

In recent years, more stringent effluent requirements have caused the conversion of numerous API separators to more efficient designs. New facilities are being engineered with these requirements in mind and are utilizing the more sophisticated of the above-discussed designs. Spill control and API separators are still used for many non-critical uses and where the effluent will be treated downstream.

Plate type systems, those utilizing coalescing tubes, and other enhanced gravity separation systems offer better performance than the simpler systems, but at higher costs (Romano, 1990). It is often necessary to balance cost versus benefits to ensure that regulatory requirements are being met. Where applications require high efficiency oil removal as well as the ability to tolerate solids, the multiple-angle plate system shows its ability to perform under difficult conditions and still provide effluent oil concentrations to meet normal regulatory requirements. Exotic systems may be required where virtually zero oil in water discharge is required.

SOLIDS SETTLING AND OIL RISING

Separation of oil and water is different than the settling separation of solids in a clarifier. Oil droplets coalesce into larger, spherical droplets, while solids agglomerate into larger masses but do not coalesce into particles that have lower surface/volume ratios like oil.

Settling of Solid Particles

The settling of solids particles in a clarifier, whether primary or secondary, is governed by Stokes's Law. This function, simply stated, is:

$$Vp = \frac{G}{(18 x \mu)} x (d_p - d_c) x D^2$$

Where: V_p = droplet settling velocity, cm/sec
G = gravitational constant, 980 cm/sec^2
μ = absolute viscosity of continuous fluid(water), poise
d_p = density of particle (droplet), gm/cm^3
d_c = density of continuous fluid, gm/cm^3
D = diameter of particle, cm

Since the equation was developed for solids falling, a particle (or droplet) rise velocity is a negative number. Assumptions Stokes made in this calculation are:

1) Particles are spherical
2) Particles are the same size

3) Flow is laminar, both horizontally and vertically

From the above equation it may be seen that the most important variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid and the particle, and the particle size. After these are known, the settling velocity and therefore the size of separator required may be calculated.

The velocity of settling or rising is dependent on the hydrodynamic drag exerted on the settling particle by the continuous fluid. This drag is dependent on the shape of the particle as well as the viscosity of the continuous fluid. This is the same sort of situation that is found in other cases where a falling object has a high surface area/mass ratio. In a vacuum, a feather falls at the same rate as a lead ball. In air or any other resistant media the ball will fall faster due to the air resistance against the feather. The same sort of phenomenon governs the settling of solid particles in a clarifier or other liquid-containing vessel. They do not perfectly obey Stokes's Law because of their particle shape.

The pure Stokes's Law calculation depends on knowing the particle size and assuming that it does not change. Solid particles flocculate into larger particles of irregular shape that settle somewhat like snowflakes. An example of the problems that can be caused by the surface area/volume ratio is the poor settling of "pinpoint flocs” in secondary clarifiers (Montgomery, 1981).

The use of Stokes's Law described above is a very simplified version of the calculations required for determining clarifier sizing. More rigorous calculations are required to take care of such functions as hindered settling. These calculations are treated extensively in Montgomery (1981).

Rising of Oil Droplets

The rise rate of oil droplets is also governed by Stokes's law. If the droplet size, specific gravity, and continuous liquid viscosity are known, the rise rate and therefore the required vessel size may be calculated.

To calculate the size of an empty-vessel gravity separator, it is first necessary to calculate by the use of Stokes's Law the rise velocity of the oil droplets. The size of the separator is then calculated by considering the path of a droplet entering at the bottom of one end of the separator and exiting from the other end of the separator. Sufficient volume must be provided in the separator so that the oil droplet entering the separator at the bottom of the separator has time to rise to the surface before the water carrying the droplet exits the opposite end of the separator.

Calculation of rise rate by this method is a gross simplification of actual conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Large droplets exhibit trailing tails much like raindrops. The tails are due to the droplet being distorted by the hydrodynamic drag noted above.

Droplet rise follows Stokes's law so long as laminar flow conditions prevail. Laminar flow regimes (in the direction of rise) prevail with small droplets. The rise rate of larger droplets may exceed the velocity of laminar flow, in which case flow begins to be turbulent. Particles of this size and larger do not rise as rapidly as would be expected from on Stokes's law. When the droplets coalesce, they do not form flocs but become larger droplets. Interfacial tension (sometimes referred to as surface tension) of the liquid tends to make the droplets assume spherical shapes since this is the smallest possible shape for a given mass.

The Stokes's Law calculation is accurate for oil drop rise in the same way that it is accurate for solids settling – only if the particle size and continuous liquid viscosity are accurately known. The problems with this calculation are therefore:

1. What is the particle size?
2. What is viscosity of the continuous liquid?

The viscosity of the continuous liquid is readily obtained from literature data. The design of such separators usually requires design over a wide variety of temperatures (and therefore viscosities) to account for summer and winter conditions as well as possible process upsets, so several viscosities may be considered during design.

The oil droplet size is much more difficult to determine. Particle sizes of solid particles are fairly easy to determine in the laboratory, but oil droplet size information is much more difficult to obtain. One tedious way to determine oil droplet sizes is to take a microscopic photograph of droplets in water and count the various size droplets. Other methods have been used with varying success, as noted by Rommel, et al (1 992) and Au, et al. (1 992). These include use of particle counters such as electric sensing zone particle counters.

It might be possible, with ultrasonic or other methods of dispersion, to generate quantities of oil droplets of generally equal size, but the droplets encountered in normal field operation vary widely in size from particles less than 5 microns (cited in Romano, 1990) to the great quantities of oil found in major oil spills.

If the droplet size is not known, or a large range of droplet sizes is present (the normal situation), how then is it possible to determine the rise rates of the droplets and therefore the size separator required?

Because the volume of oil in a droplet is proportional to the cube of the diameter, it follows that very small droplets contain extraordinarily small quantities of oil. We may therefore confine ourselves to the examination of oil droplets large enough that the quantity of oil represented by them may cause environmental problems if discharged into surface or subsurface waters. Oil should not be present in quantities great enough to cause oil sheens or even in the small quantities required to show more than 15 ppm on the standard EPA tests. Many jurisdictions, including King County, WA (Seattle) have enacted standards allowing discharge oil levels considerably less than the EPA limit of 15 ppm oil and grease in the water discharged. In order to minimize the possibility of such discharge, it is wise to proceed carefully and cautiously in the design of oil-water separator systems.

SELECTION AND DESIGN OF OIL-WATER SEPARATOR SYSTEMS

General Design Considerations

Numerous factors must be considered in the selection and design of oil-water separation system!,. Among these are:

1. Flow rate and conditions
2. Degree of separation required - effluent quality
3. Amount of oil in the water
4. Existing equipment
5. Emulsification of the oil
6. Treated water facilities
7. Recovered oil disposal method

For industrial and some municipal applications, flow rate, amount of oil, flowing temperature, and other conditions affecting separation such as whether flow is laminar or turbulent may be easily determined. For stormwater applications, however, it may be necessary to estimate water flow quantities. The degree of separation required is usually a matter of statutory or regulatory requirements, but if the water is discharged to a POTW or industrial treatment plant it may be negotiable.

The amount of oil in the water may be known, especially in industrial applications, but it will often be necessary to estimate the quantity in stormwater applications. Equipment manufacturers can provide guidance about quantities to be expected, and some information has been published about stormwater quality (Hunter, et al., 1979, Hoffman, et al., 1982, Wakeham, 1977, and Stenstrom, et al., 1984).

Existing equipment such as ARI separators may affect the design of equipment to be used. Often it is possible to retrofit existing equipment with more sophisticated internals to enhance separation quality. The degree of emulsification of the oil is difficult to assess, but steps can be taken to discourage the formation of emulsions and encourage the breakup of emulsions that are inadvertently created. It may be necessary to substitute quick-break detergents for conventional detergents that are also emulsion causing. Quick-break detergents are those detergents designed to remove the oil (or grease) from the item to be cleaned and then quickly dissociate again from the oil, leaving the oil as free hydrocarbon droplets in the water.

It is necessary to ensure that adequate size piping is provided for downstream treated water removal to avoid flooding the separator and perhaps filling the oil reservoir with water. A downstream test point should be provided to allow for effluent testing. Adequate storage facilities for the removed oil should be provided and means for recycling the oil included. Careful records of removed and recycled oil should be kept to avoid possible future regulatory problems.

The following is a discussion of several of the points touched briefly on above concerning design of oil-water separation systems.

Emulsions and their Properties

An emulsion is a mechanical mixture, not a solution, consisting of droplets of one immiscible fluid dispersed in another continuous fluid. A good definition, offered by Love (1948), is: "An emulsion is an apparently homogenous mixture in which one liquid is dispersed as droplets throughout a second immiscible liquid." In the case of water and oil, two types of emulsion are common, depending on which is the continuous phase (Love, 1948).

1. Oil in water emulsions.
2. Water in oil emulsions.

A third type, water in oil in water, is possible but very uncommon.

Many emulsions will separate by gravity if given the necessary time, however some are so dispersed that they will virtually never separate if undisturbed. Examples of this type emulsion occur in oil field and chemical waste products (Love, 1948).

The property describing the separability of emulsions is referred to as the stability of the emulsion. Very resistant emulsions are referred to as “tight" emulsions. Several factors affect the stability of emulsions (Love, 1948):

1. The emulsifying agent
2. The viscosity of the continuous phase
3. The differential specific gravity of the two phases
4. Relative percentages of the two phases
5. Age of the emulsion

Often, the major influence on the stability of emulsions is the emulsifying agent. The substance that holds two immiscible fluids bound tightly together is an emulsifying agent (Woodruff, 1962). Emulsifying agents include surfactants, (both natural and artificial), iron oxide, iron sulfide, paraffins in the oil, bacteria, and dirt (Woodruff, 1962).

Bacterial growth and emulsions seem to be linked. Green and Trett (1989) note that, in a study of growth of freshwater bacteria on hydrocarbons, emulsification of the hydrocarbons was found in every case where bacterial growth occurred. Bacteria which could not produce extracellular emulsifying agents were not capable of growth utilizing a crude oil substrate.

The separation properties of the emulsion depend greatly on the viscosity of the continuous phase. In oil-water separation, this is usually the water phase. Bansbach (1970) notes that the viscosity of the continuous phase plays a dual role:

1. In a low temperature (and therefore relatively high viscosity) environment, a given amount of agitation will not break up the oil phase into droplets as numerous or as fine as in the case of a higher temperature, lower relative viscosity system.

2. Viscous continuous phase liquids hinder the separation of the mixture because the droplets must overcome more viscous drag in their journey to the top of the mixture.

The viscosity of the oil phase also has an effect on the emulsion in that higher viscosity oils retard the movement of emulsificant to the surface of the droplets. This retards the aging effect on the stability of the emulsion, thus making the emulsion easier to treat (Bansbach, 1970). If the specific gravity of the oil is very close to that of the water, then there is little gravitational driving force for separation of the emulsion.

Temperature has a dual effect on settling rate: it affects the viscosity and the differential specific gravity (Love, 1948). It is also believed that as temperature increases, the resulting expansion of the oil drops causes stress on the film of the emulsificant and at high temperature may cause it to rupture (Bansbach, 1970).

Age of the emulsion seems at first glance to be a property that would not be expected to affect the stability of the emulsion. As an emulsion ages, the surface-active agent (surfactant) which causes the emulsion tends to migrate to the interface. The surfactant concentrates at the interface between the oil and water, thus strengthening this interface (Bansbach, 1970). It is preferable to separate the oil and water at the earliest possible moment to avoid this problem. For this reason, it is often best to provide on-line oil water separators instead of collecting the oil-water emulsion and treating it batch-wise.

Influent Conditions

Much of the performance of an oil-water separator depends on the influent conditions. Because smaller droplets are more difficult to separate, equipment or conditions that form small droplets in the influent to the oil-water separator will cause the separator to be designed larger to accommodate the additional time required for the smaller droplets to coalesce. Conditions that form small droplets are any conditions that cause shear in the incoming water. The following are (more or less in order of severity) some factors that can cause small droplet sizes.

1. Pumps, especially centrifugal pumps
2. Valves, especially globe valves
3. Other restrictions in flow such as elbows, tees, other fittings or simply unduly small line sizes
4. Vertical piping (horizontal is better). Emulsifying agents as discussed elsewhere in this paper greatly contribute to small droplet sizes in addition to discouraging coalescence.

Ideal inlet conditions for an oil-water separator are:

1. Gravity flow (not pumped) in the inlet piping
2. Inlet piping sized for minimum pressure drop
3. Inlet piping straight for at least ten pipe diameters upstream of the separator (directly into nozzle)
4. Inlet piping containing a minimum of elbows, tees, valves, and other fittings.

Most separators are provided with an inlet elbow or tee inside the separator pointing down. This is an exception to the above rules and is intended to introduce the influent water below the oil layer on the surface, thus not disturbing the surface oil and re-entraining some of it.

While gravity flow conditions are not often obtained except in POTWS, stormwater, or some process water applications, a positive displacement pump such as a progressive cavity type pump may be used as they provide minimum disturbance of the fluid.

Inlet piping should be as smooth as possible to avoid turbulence caused by pipe Toughness. Smooth PVC is preferable to rough concrete.

Sometimes anti-emulsificant chemicals are utilized, but extreme care must be exercised in the use of these chemicals to ensure that they do not make the emulsion worse instead of improving it.

If large quantities of solid particles are expected, it is wise to provide a grit removal chamber before the separator. These chambers should be designed according to normal design parameters for grit removal as used in POTW plant design.

Effluent Conditions

Effluent designs are also important in the operation of oil-water separators. Downstream piping and other facilities must be adequately sized to process the quantity of water (and oil) from any likely event. Manholes overflowing during a heavy rainstorm will surely cause any oil that has accumulated to be re-released into the environment.

Effluent piping must be designed with siphon breaks so that it is not possible to siphon oil and water out of the separator during low flow conditions. One way to do this is to provide the sampling/overflow tee in the effluent line as shown in Figure 1. If the effluent arrangements are not properly designed, a vortex from the effluent pipe can "reach up" to the interface and cause discharge of oily effluent water even if the interface is clear (Bansbach, 1970). Oil must be removed manually from spill control separators by a maintenance crew equipped with a vacuum truck or other equipment for oil removal. If this is not done on a regular basis, this oil may become re-entrained at the next rainfall event and reintroduced into the environment (Romano, 1990).

Removing the oil from the separators is not enough to protect the environment, it must also be re- cycled to ensure that it is disposed of properly. Current U.S. law can hold the owner of the oil-water separator responsible if this oil is not properly disposed of, even if the owner has paid for proper disposal.

SUMMARY AND CONCLUSIONS

Environmental regulations are steadily becoming more restrictive and requiring lower concentrations of hydrocarbons in effluent water. The EPA's new stormwater regulations require treatment of stormwater not currently treated. Some localities require lower effluent standards than even the EPA mandates.

Unfortunately budgets for wastewater treatment are always very limited, so it is becoming necessary to provide more effective treatment without increasing capital and operating costs.

Sometimes treatment systems can be as simple and inexpensive as spill control separators. In rare cases, it may be necessary to provide costly, elaborate, methods of treatment such as reverse osmosis systems. The most appropriate method of treatment is the least expensive method that provides the required effluent quality.

Fortunately, engineering advances are being made that will help to alleviate the problem of having to provide very costly treatment systems. One of the best ways to ensure regulatory compliance is to provide a complete computer simulation of the wastewater treatment system. A proper simulation will allow the engineer to choose a system that meets the requirements without undue over-design and additional cost.

Multiple-angle coalescing plates used in conjunction with properly designed separators and influent/effluent systems provide a cost effective method of ensuring effluent water quality that meets or exceed the requirements of federal, state, and local regulations. To ensure proper sizing, each system should be individually designed to meet all customer requirements.

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APPENDIX:

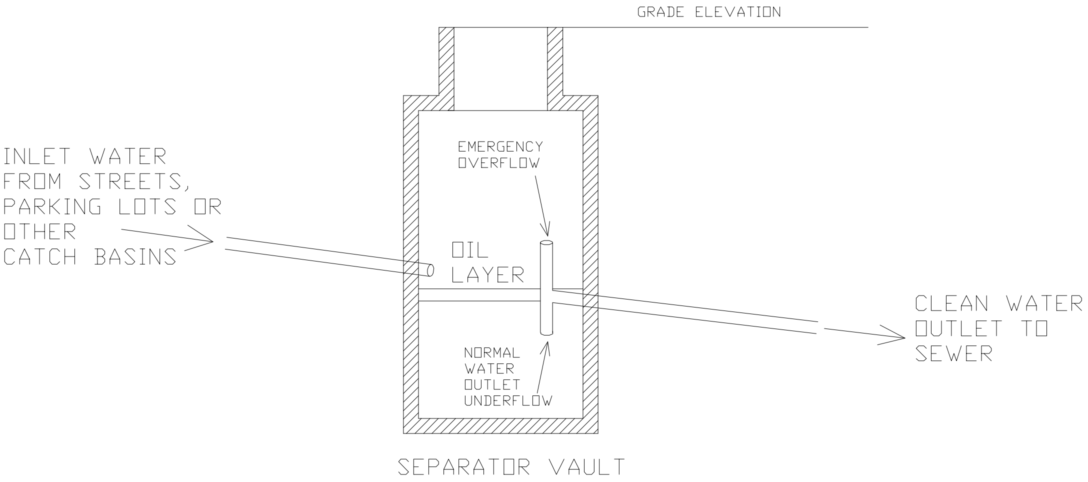


Figure 1. Spill Control Separator

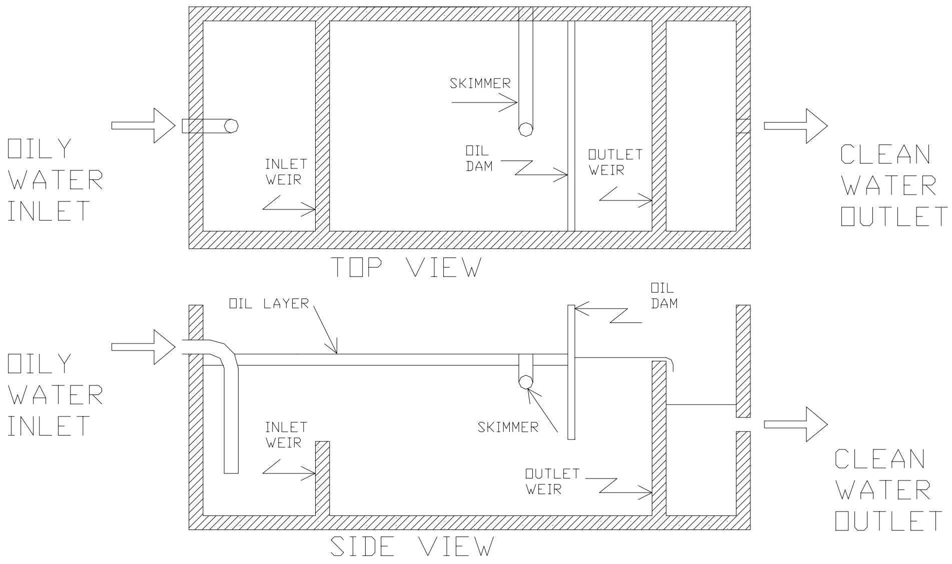
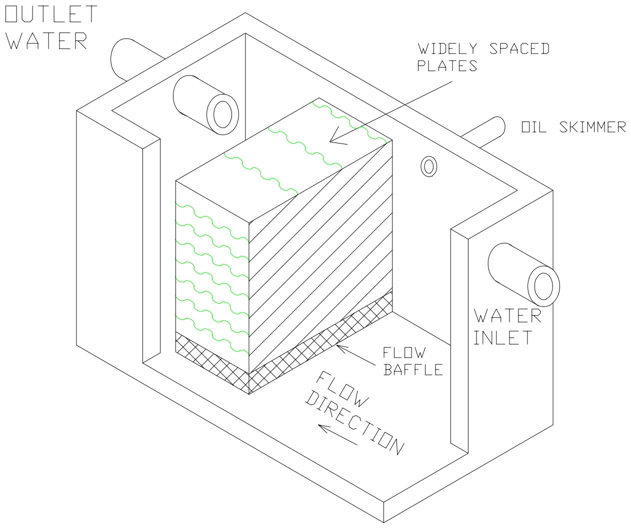
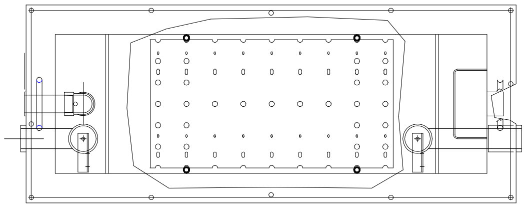


Figure 2. Typical American Petroleum Institute (API) Separator Pit

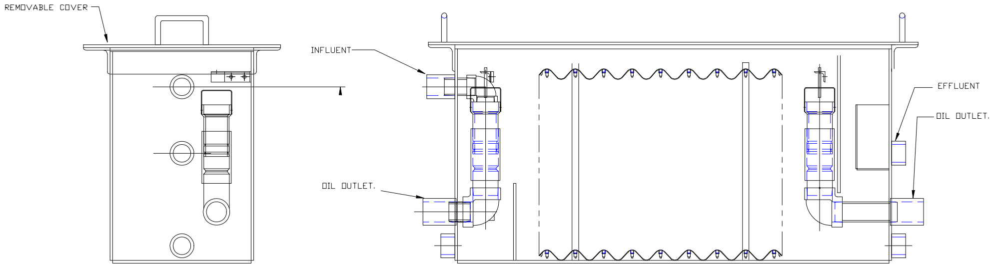


NOTES:
1. FLOW BAFFLE PROVIDED UNDER PLATES TO PRECLUDE FLOW UNDER THE PACK AND PROVIDE SPACE UNDER THE PACK FOR SEPARATED SOLIDS STORAGE.
2. FIGURE PROVIDED WITH HALF OF PLATES REMOVED TO SHOW FLOW BAFFLE.
3. INLET AND OUTLET PROVIDED WITH FLOW DISTRIBUTORS (NOT SHOWN)

Figure 3. Inclined Plate Separator



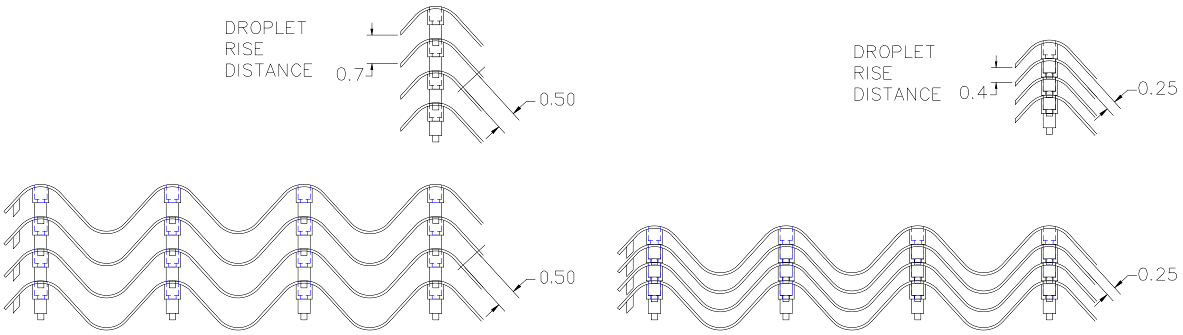
TOP VIEW



END VIEW

SIDE VIEW
(LESS SIDE PLATE)

FIGURE 4: FLAT CORRUGATED (HORIZONTAL SINUSOIDAL) SEPARATOR



NOMINAL 1/2"
SPACING

NOMINAL 1/4"
SPACING

Figure 5. Flat Corrugated (Horizontal Sinusoidal) Plate Pack

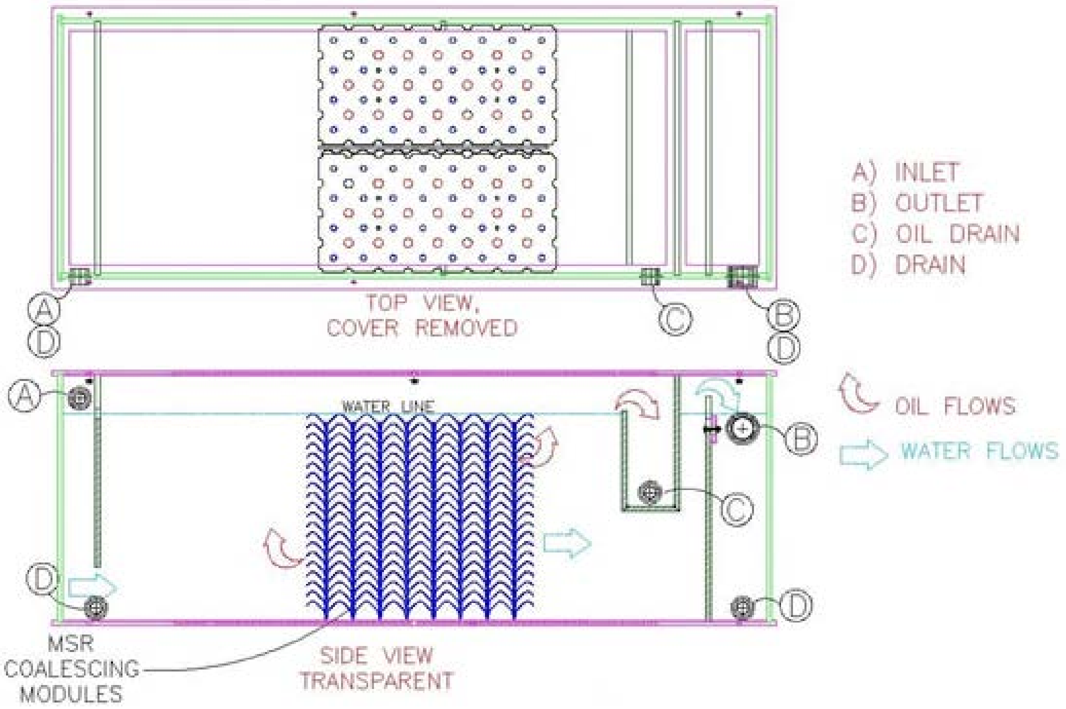


Figure 6: Multiple Angle Plate Separator – MSR-11P

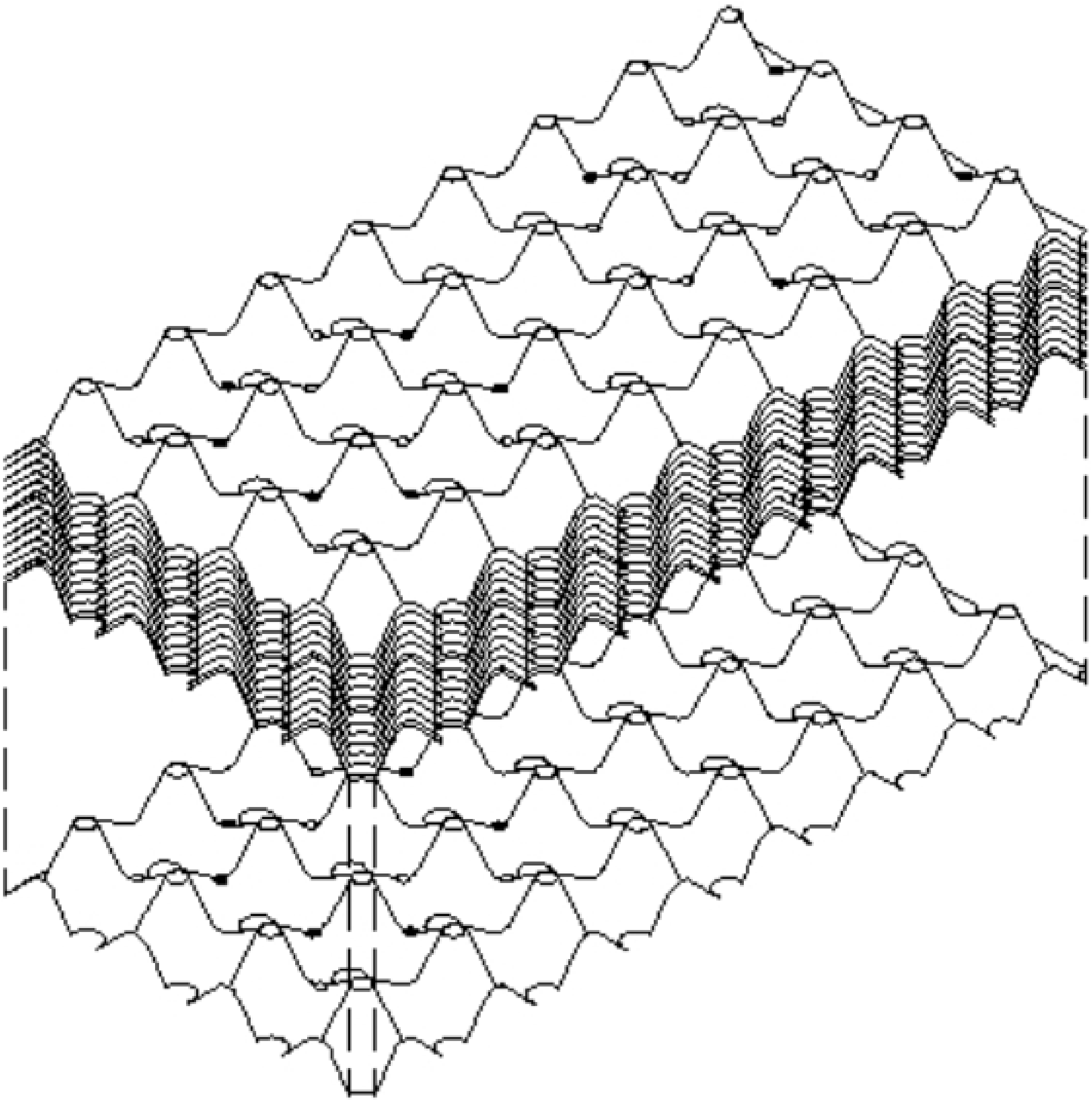


Figure 7: Multiple Angle Coalescing Pack

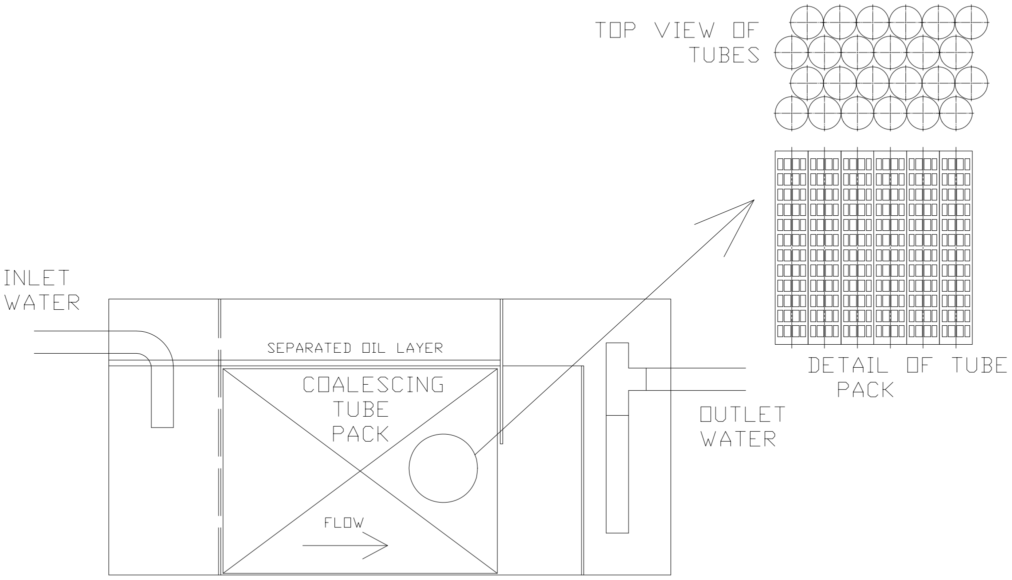
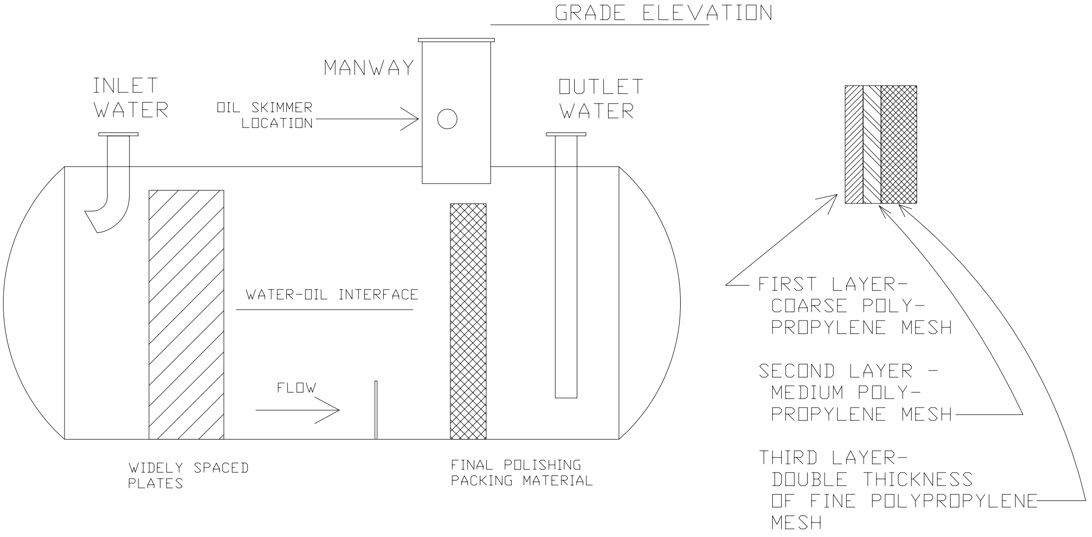


Figure 8. Coalescing Tube Separator



DETAIL OF PACKING MATERIAL

Figure 9. Packing Type Separator