OIL-WATER SEPARATORS FOR STORMWATER PROCESSING – PROTECTING THE ENVIRONMENT WITHOUT THE HIGH COSTS OF MAINTENANCE

Kirby S. Mohr, P.E.
Mohr Separations Research, Inc.
1278 FM 407 Suite 109
Lewisville, TX 75077
Phone: 918-299-9290 Cell: 918-269-8710

ABSTRACT: Environmental regulation of oil in water discharges is increasingly becoming more stringent. Stormwater processing systems have a number of possible applications for coalescing plate separators. These applications include various industrial plant facilities and commercial facilities, or anywhere that it is necessary to process contaminated stormwater. In the case of industrial plant facilities, the contaminated water must be treated if discharged to surface waters in order to meet the "no sheen" requirement of the Clean Water Act (CWA). Stormwater discharges were covered under the CWA but not required to have permits under the system until 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. These 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 permit.

The purpose of this paper is to offer suggestions for specifying and designing separation systems to meet the requirements for treating contaminated waters. Overall, oil-water separator system designs are discussed and recommendations for ensuring system efficiency, regulatory compliance, reliability, sustainability and effective procedures are presented.

Keywords: Oil-Water Separator, stormwater processing system, wastewater, rainwater, specification, design, industrial plant, commercial facilities, stormwater discharge

TABLE OF CONTENTS

BACKGROUND AND INTRODUCTION

Many industrial and commercial facilities may or may not have dedicated stormwater processing systems. Stormwater may be contaminated with oil or other hydrocarbons, which need to be removed before returning the water into the process cycle. Most of this pollution comes from the mixture of leaked or spilled oils associated with industrial facilities or even commercial facilities (truck depots, large service stations, etc.). Hydrocarbons that become present in any effluent water need to be removed in order to protect wetlands, streams, and lakes from possible contamination. These large quantities of sediments and other contaminants also enter surface waters by rainwater runoff and snowmelt. Bennett, et al, (I 981) notes that "Contributions of organic pollutants and suspended matter from stormwater are significant and are quite important for highly developed areas. Stormwater produces instantaneous shock loadings on a stream and result in short-term very high pollutant concentrations."

In the United States, much of the water that falls during rainstorms goes directly to surface bodies of water by dedicated storm sewers. Some rain flows directly into the surface water by streams and culverts, and some of the water enters the surface water by Combined Sewer Overflows (CSOs). Oil and grease, heavy metals, and other contaminants found in rainwater and snowmelt can be very toxic to aquatic life and detract from the pleasurable use of streams, lakes, and bays. Many communities, especially the largest ones, utilize surface water for drinking water supplies and contaminants can be very difficult to remove for drinking water standards.

It is necessary to remove the oil from the water before it may be discharged from these facilities in order to meet the Clean Water Act. The purpose of the following information is to provide some guidance on the nature and quality of the stormwater to be expected and to offer some design suggestions for the pretreatment of stormwater, prior to discharging the source.

LAWS AND REGULATIONS

Oil in water discharges from industrial and other facilities are governed by a variety of federal, state and local laws. Included in these laws 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).

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 extensively amended 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, the National Pollutant Discharge Elimination System (NPDES) permit method was created. Permits for point sources under this system are granted by the Environmental Protection Agency (EPA) or by states with EPA

> The Clean Water Act (CWA) regulates the discharges of pollutants into US waters as well as the quality standards for surface waters.

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 (POTWs, also known as sanitary sewer treatment plants) and toxic discharges from industrial plants, it also controls the discharges of petroleum and other hydrocarbons into the waters of the United States.

The Clean Water Act directly governs the effluent from all facilities if the effluent is not further treated. If the effluent from the facility is further treated downstream, either at a public or private treatment plant, the Clean Water Act governs the effluent from that plant. In circumstances such as this, the management of the treatment plant controls the allowable effluent from the facility (which is entering their treatment plant). It is often possible to check with the engineers at the treatment plant and find out the allowable oil content discharge.

Most POTWs set their inlet criteria substantially above the Clean Water Act requirement because the oil in the effluent from the facility is significantly diluted by mixing with the other inlet water. The criteria for water entering the POTW's tends to range from 75 mg per liter of oil allowable up to about 200 mg per liter allowable, but some plants still have lower allowable oil thresholds.

In the event of direct discharge to lakes or rivers, most states and localities require discharges to contain 15 ppm or less of 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 10 ppm (Romano, 1990).

In Canada, local regulations and the Fisheries Act govern the discharge of contaminants into any body of water which “either contains or may contain fish” (Government of Canada, 1978).

APPLICATIONS FOR STORMWATER PROCESSING SYSTEMS

Industrial Facilities

Industrial facilities have a number of possible applications for stormwater processing systems. Industrial tank depots, plant process drains and outfalls, and even process optimization techniques can utilize oil-water separators for contaminated stormwater. It is not uncommon to have oil spills and leaks that can occur throughout the various operations of the facility. Oil may leak from storage tanks, lubricated equipment, or even during production processes. Some plants will have collection basins or other precautionary equipment when oil is leaked or spilled. Often, a large spill will be washed down with one or more firehoses. Contamination will occur from the mixture of oil and water and this wastewater will need to be treated. Some industrial facilities will also have vehicle maintenance operations. Most oil leaks will come from diesel and gasoline engines. It is inevitable for stormwater to blend with the leaked oils and the resulting mixture will need to be processed before discharging.

Absorbents are not suitable for use in situations where there is the possibility of a spill because they have very limited capacity and are quickly spent. Maintenance departments seldom replace absorbents as often as necessary, partly because of pressing other work and partly because of the cost of fresh absorbents and also the cost of disposing of spent absorbent pads or pillows. Coalescing separators do not have these problems because the media is permanent and the recovered oil is generally recyclable.

Commercial Facilities

Truck depots provide a number of different commercial vehicles for many customers. They operate very similar to dealerships. Most of the vehicles are placed in large parking lots where stormwater collects and can become polluted with leaked oils and other hydrocarbons. Construction sites are another potential source for contaminated stormwater. Stormwater can cause soil to erode and the resulting water will contain various sediments.

Some industrial and commercial facilities will also have vehicle maintenance operations. These facilities will need to install a system for the removal of hydrocarbons from their wastewater. The contaminated water can result from either oil changing stations or vehicle washing locations.

As data on contaminant levels was accumulated, regulations were written to take into account not only for the public health aspects of stormwater contamination, but also for the adverse effects on the environment. The result was that regulations have become more stringent. Table 1 provides some data on the typical contaminant concentrations in stormwater and the matching regulations. Please note that the metallic contaminants in the water are found mostly in the particulate matter carried by the water.

TABLE 1: COMPARISON OF TYPICAL STORMWATER POLLUTANT CONCENTRATIONS TO WATER QUALITY CRITERIA CONCENTRATIONS

Concentrations, µg/l or ppb					Particulate Fraction	USEPA/Washington Dept of Ecology Standards, Freshwater	
Pollutant	Commercial	Industrial	Residential	Highway		Acute	Chronic
Cadmium	5	5	<3	<3	60%	0.60	0.32
Copper	245	105	20	100	60%	3.9	3.0
Lead	380	245	210	1780	90%	10.5	0.41
Zinc	275	275	120	400	60%	30.0	27.0
Oil/Grease	15 ppm	480(5)	<5(5)	90(5)		10 ppm	
Fecal Coliforms	980 orgs /100 ml					50 orgs /100 ml	

Notes: 1) Particulate fraction values apply to concentration date for commercial and industrial uses only.
2) Acute Criteria for freshwater at a hardness of 20 ppm.
3) Standards are receiving eater standards except oil and grease.
4) Oil and grease and coliform standards Washington State Department of Ecology
5) Source: City of Seattle Engineering Dept. (Paston, 1994)

Source: Stormwater Management Manual for Puget Sound Basin, 1992

The following further discusses some of the contaminants that may result from stormwater runoff water at various facilities.

Hydrocarbons:

Most of us have seen an oil slick "rainbow" on the water runoff in a parking lot during a rainstorm. Buchholz (1994) notes that urban runoff (as opposed to agricultural or other non-point sources) is the most significant contributor to the environment of hydrocarbons. In addition to runoff from parking lots, rainwater runoff from large service stations, highways and bridges, and industrial sites contribute to the hydrocarbon content of the rainwater.

A private unpublished study by Facet International, Inc. (McDowell, 1995), concerning separation of used motor oil from water, indicated that some hydrocarbons were attached to the solid particles in the oil. Microscopic evaluation indicated that these particles were mostly iron oxide and carbon, evidently from engine wear and carbonization of the oil, although some of the particles were probably solids removed from the combustion air. This study partially confirms data from Hoffman, et al (1982), which indicates that hydrocarbons in stormwater are primarily associated with particulate material. The McDowell data leads to the conclusion that there is a limit to the amount of oil that may be attached to the solids present in water and that additional hydrocarbon (the greater percentage in some stormwater) exists as free droplets. The hydrocarbons discussed in the Hoffman study were in low ppm concentrations, and those in the McDowell study above 100 ppm (inlet), so the data tends to confirm the above conclusion.

Hunter, et al., (1979) reported: "The storm-sewer loading from an area representing 0.83% of the total Philadelphia urban area represented three quarters of one of the seven refineries in the same area. Their calculated hydrocarbon pollutant loading for the study area was 22.9 lb/year/acre. This data would tend to support the assertion made above that rainwater is a very important source of hydrocarbons in the environment. It is also recognized that hydrocarbons exist in snowmelt runoff, but not to as great an extent as are found in rainwater (Bennett, et al, 1981).

Heavy Metal Contaminants:

Heavy metals of concern are Copper, Lead, and Zinc. Heavy metal concentrations seem to be related to pH and hardness of the stormwater (EPA, NURP, 1983).

A report by the EPA (EPA, 1992) on the San Francisco Estuary Project indicated that most pollutants in the estuary were due to agricultural and forest management activities, but that urban runoff was the most significant contributor for lead and hydrocarbons.

Buchholz (1994) agrees that lead in rainwater is most significantly contributed by urban environments. A private study made of samples of street gutter sediment collected at sites in the city of Coral Gables, Florida, showed copper contents from 40-350 mg/kg, lead contents of 60-500 mg/kg, and zinc contents from 500-1600 mg/kg (Gamble, 1994). This indicates that street sediment may be a significant contributor of metals.

Heavy metals are much less toxic to fish in hard water than they are in soft water. This is mostly because of complex formations between heavy metals and carbonate and bicarbonate ions, although complex formations with organic agents, such as humic and fulvic acids also occurs. As an example, below pH 6.5, copper in water can exist at free copper ion. At higher values, it will tend to complex as $CuCo_3$. Because the hardness of the water affects the carbonate available to complex, copper in water is more toxic to fish in softer water than in harder water (Snoeyink and Jenkins, 1980). Krenkel and Novotny (1980) note that hardness decreases the toxicity of heavy metals.

These various contaminants have been shown to have adverse effects on human beings as well as aquatic life. Concentration levels as low as 10 to 100 micrograms per liter have been shown to adversely affect aquatic organisms by altering processes such as feeding or reproduction (Romano, 1990). Table 2 below shows some possible adverse effects and recommended criteria.

TABLE 2: TOXIC EFFECTS OF STORMWATER CONTAMINANTS

Contaminant	Effect on Humans	Recommended Criteria	
		Drinking Water	Aquatic Life
Lead	Nephritis	50 µg/liter	0.01 LC_{50}
Zinc	Metallic taste	5 mg/liter	0.01 LC_{50}
Copper	Liver damage	1 µg/liter	0.01 LC_{50}

Table adapted from Krenkel and Novotny, 1980.

Five categories or groups of impurities that are hazardous to aquatic life (Fair, et all, 1971) are:

1. Matter that settles and deprives fish of food by depositing a carpet of pollution on the bottom of streams and lakes.
2. Substances that exert sufficient oxygen demand to lower the dissolved oxygen (DO) content below the level needed.
3. Compounds that raise pH above 8.4 or lower it below about 6.8, more or less, may be directly lethal. Changes in pH may reduce tolerances of fish to high temperatures and low DO levels.
4. Wastes that increase salinity and with it, osmotic pressures, such as oil-well brines.
5. Specifically toxic substances, such as pesticides.

Sediments:

Muddy water, roiled by suspended clay and other sediments, is both troublesome to fish and obnoxious to people, especially people who do not live in areas where, according to Mark Twain, "a tumblerful of river water contains an acre of land."

Buchholz (1994) notes that in many stormwater monitoring programs: "Sediments were the most critical and frequently observed pollutant in stormwater flows." The State of Washington Department of Ecology notes that "sediment from erosion was the primary stormwater quality problem." Livingston, (I 989) notes that: "Excessive sediment blocks Stormwater conveyance systems, plugs culverts, fills navigable channels, impairs fish spawning, clogs the gills of fish and invertebrates, and suppresses aquatic life."

In a study done in Philadelphia, PA, Hunter, et al, (1979) reported suspended solids content from 26 to 118 mg/L, with an average of 87 mg/L. It is likely that in many areas, sediment contents are greater than this. Snowfall is not as important a source of solids because suspended solids loading for snowfall precipitation are approximately one half those for rainfall (Bennett, et al, 1981).

Since researchers have found that hydrocarbons tend to partition to the solids in a rainwater stream, and many of the particles are automotive exhaust particles, (Eaganhouse, 1981), removal of sediments should also tend to help reduce the hydrocarbon content of the rainwater. Conversely, failure to remove the particles from the rainwater should allow some of the hydrocarbons to pass through a separator. Sediments can also contain heavy metals. Sediments in water can contain nutrients and provide substrate for bacterial growth, unwanted in Rainwater Harvesting Systems.

Nutrients and Pesticides:

Nutrients in storm water have not been much discussed in this paper because the contribution of nutrients, nitrogen, and phosphorous are relatively small for (urban) stormwater flows (Bennett, et al., 1981). Pesticides, while of some importance in urban stormwater, are much more important in agricultural and forest management stormwater.

SOLIDS SETTLING AND OIL RISING

Separation of oil and water is different from the settling separation of solids. 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 is governed by Stokes’s Law. This function, simply stated, is (Perry, 1963):

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

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

Because 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, one can see 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. Solid particles present in maintenance systems do not perfectly obey Stokes's Law because of their particle shape.

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 the rise velocity of the oil droplets by the use of Stokes's Law. 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. 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 (the API Method requires 45 minutes of residence time).

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.

Droplet rise-rates follow Stokes's law as long as laminar flow conditions prevail. Laminar flow regimes (in the direction of rise) exist with most droplets. The rise rate of larger droplets may exceed the velocity of laminar flow. When the droplets coalesce, they do not form flocs as with solids. Instead, they coalesce to become larger droplets. Interfacial tension (sometimes referred to as surface tension) of the liquid allows for the assumption of spherical shaped droplets since this is the smallest possible shape for a given mass.

According to the API method listed in publication 421, the calculation for the performance of the separators assumes the use of a 45 minute residence time for the removal of the oil. It further assumes the use of Stokes's law in the droplet size removal calculation. One of the preconditions for Stokes's law is laminar flow, and this condition is seldom, if ever, met in an API separator because of convection currents and other flow currents that preclude the orderly rising of small droplets. Large droplets rise well, but the small ones do not.

The API separator calculation method was originally designed, in 1947, for the removal of oil from refinery effluent streams for resource recovery, and was not intended for removing oil down to levels required by environmental laws. The API's own survey notes that most of their members' separators do not remove oil to less than about 150 mg/L, which does not meet the Clean Water Act.

The oil droplet size is difficult to determine with any accuracy. Particle sizes of solid particles are fairly easy to determine in the laboratory, but oil droplet size information is much more difficult to obtain because most of the methods for determining sizes change the droplet size.

Even if the droplet size is unknown, or a large range of droplet sizes is present (the normal situation), it is still possible to determine the rise rates of the droplets and, thus, the size separator required by judicious application of conservative assumptions. This is discussed below.

Oil in the outlet should not be present in quantities great enough to cause oil sheen if the effluent is not directed to a sanitary sewer. 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.

SYSTEMS AVAILABLE FOR REMOVING OIL FROM WATER

Systems for removing oil from water range from very simple tanks to very elaborate membrane technology-based systems. For most applications in removing oil, the simplest systems are inadequate (although often used) and the most complicated are either too expensive or too maintenance-intensive, or a combination of both. Therefore, most of the following information provided will concentrate on methods of separation intended to meet regulatory requirements with minimum cost and maintenance.

Gravity Separation

One of the simplest possible separators is an API separator. In 1947, the American Petroleum Institute (API) commissioned a study by the University of Wisconsin that provided design criteria for an oil-water separator system intended for gross oil recovery at the water outlet of oil refineries. A diagram of a typical API separator is shown in Figure 1 below (Adapted from API Publication 421, 1990).

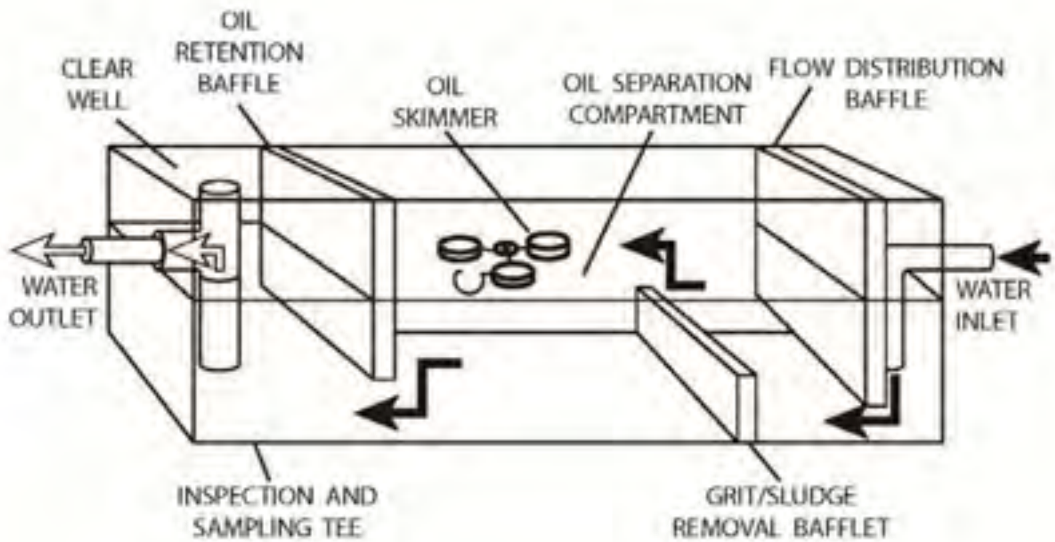


Figure 1: API Separator

Systems are often sold as “API type separators”, which commonly means that they have the same universal baffle arrangement as a regular API separator, but do not conform to the design criteria of a 45 minute residence time (established by the API). Separators which have a lesser residence time (and are therefore smaller and less expensive than rigorously designed API separators) do not meet the API design criteria and, therefore, cannot be expected to meet the API’s modest effluent expectations.

Advantages of the API and API type separators 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 quality separation than is possible with simple gravity separators, while still maintaining the low capital and maintenance cost benefits of the simpler systems. In many ways, the enhanced gravity separators substitute sophisticated design and internals for the settling time provided in pure gravity separators. These enhanced gravity separation systems have some similarity to API separators, but include coalescing media that enhances the separation of the oil and water.

Multiple Angle Plate Separators

Multiple angle plate separators such as the MSR *HE-Media* systems were developed to take advantage of the effects of gravity to the fullest and optimize the oil removal process.

A drawing of a typical above-ground multiple angle separator at a maintenance facility is provided below in Figure 2.

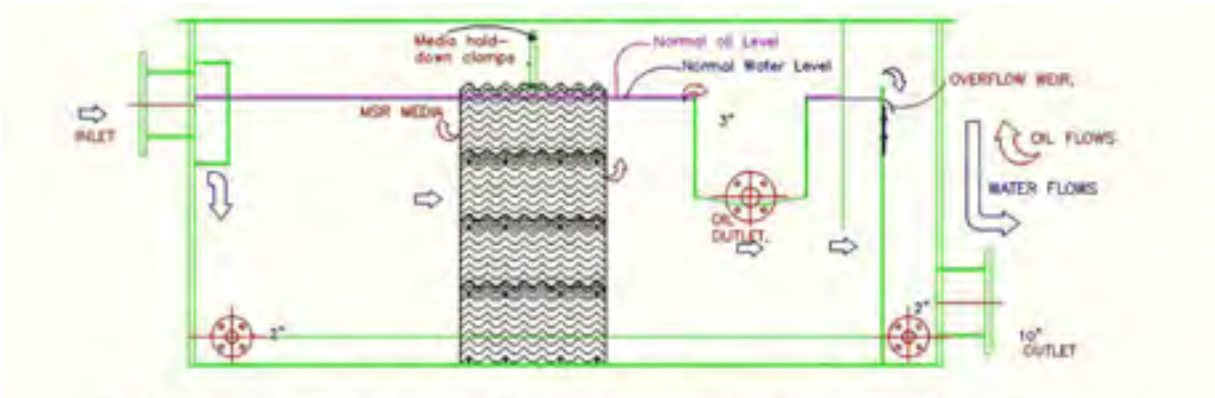


FIGURE 2: TYPICAL ABOVE-GROUND MAINTENANCE FACILITY SEPARATOR

The coalescing plates are corrugated in both directions, making a sort of "egg-carton" shape. This is done so that all of the underside surfaces slope upward, encouraging captured oil to move toward the surface. Spacers are built into the plates for two vertical spacing sizes (8 mm and 16 mm). The narrow spacing is more efficient and the wider spacing is more tolerant of solids.

The specifying engineer should be cautious of the use of any type of separator which includes coalescing mesh, coalescing pads, or coalescing tubes. This is because the coalescing mesh and coalescing pads, if they are finely woven or otherwise dense enough to operate, can easily become plugged with solid particles -- or more likely -- a combination of solid oil particles. Coalescing tubes depend on oil droplets passing and impacting on the plastic of the tubes, being captured there, and eventually migrating to the surface. The streamlines of the flow, however, tend to carry the oil droplets around the solid portions of the tubes. This defeats the theory of how the tubes operate.

Applications of the Different Systems

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

Coalescing plate separation systems offer better performance than the simpler systems, but at higher costs (Romano, 1990). It is often necessary to balance the cost versus the benefits in order to meet the regulatory requirements. Where applications require high efficiency oil removal as well as the ability to tolerate solids, MSR coalescing plate systems have proven sustainability under difficult conditions and still provide effluent oil concentrations that meet the normal regulatory requirements.

Advantages of the multiple-angle plate separator system are:

1) The plates are designed to shed solids to the bottom of the separator, avoiding plugging and directing the solids to a collection area. The solids drop directly to the bottom of the separator. If desired, troughs to collect the solids can be incorporated.
2) The double corrugations provide surfaces that slope at a 45° angle in all directions, so that coalesced oil can migrate upward.
3) The holes in the plates that constitute the oil rise paths and solids removal paths also provide convenient orifices for inserting cleaning wands. Other types of pack systems are not available with such holes and are more difficult to clean when plugged with the solids.

SPECIFYING COALESCING SEPARATORS FOR STORMWATER PROCESSING

There are a number of components that affect the design of coalescing separators for stormwater processing systems. These include the water flow rate, water temperature, amount of oil present in the water, and the use of existing equipment (if applicable), and others.

Flow Rate

The *Rational Formula,* shown below, can be used to estimate the flow rate of various rain intensities. The coefficient noted in this formula is dependent upon the ground surface type, but for paved areas 0.95 is often used.

Rational Formula: $Q=ciA$

The *Rational Formula* requires the following units:

Q = Peak discharge, cfs
c = Rational method runoff coefficient
i = Rainfall intensity, inch/hour
A = Drainage area, acre

The rainfall intensity can be obtained from the rainfall intensity maps (5 year duration for U.S. and Canada), and the surface area (ft^2) of the rainwater is utilized in the *Rational Formula* to provide the necessary corrected runoff flow (CFS or US GPM). It is usually assumed that there is approximately 100 mg/L of oil in the rainwater, and the average droplet size is about 120 µm.

Some jurisdictions require the use of a longer return period storm, such as a 10 year storm, and some allow the use of a shorter return period storm. For a given installation, it is advisable to consult local authorities to determine what design storm should be used.

In the case of a large spill, it is assumed 5000 parts per million of oil content and 260 μm for the average oil droplet size. Often, a spill will be washed down with one or more firehoses, approximately 50 gal/min per firehose, and a custom separator can be designed to manage whatever flow is expected, based on local practices for washdown.

MSR generally uses 0.83 as an estimate for the hydrocarbon specific gravity. This is typical for jet fuel.

The flow rates for parking lots at both industrial and commercial facilities are also estimated utilizing the *Rational Formula*. Numerous factors affect the oil content of the water, including the intensity of the storm, the time since the previous storm, and size and intensity of any possible oil leaks. This implies a great deal of variation in the oil content, and MSR has found that the 100 mg/L can be used for satisfactory designs in normal cases. MSR generally utilizes an operating temperature of 32°F and an oil specific gravity of approximately 0.85. This is equivalent to diesel fuel or a diesel fuel and lubricating oil mixture.

Operating Temperature

The operating water temperature is an important variable in the design because it governs the viscosity of the water. This is usually known, or may be measured, but if it is unknown (in cold climates), a reasonable attention is 32°F. This is the most conservative, worst case possible. In milder climates, a reasonable assumption is 55°F because it is generally the average groundwater temperature worldwide.

Oil Content

The oil content is seldom known, and varies wildly with the operations of the electric utilities. Mohr Separations Research has historically used 1000 mg per liter (0.1%). This was based on some conversations with a municipal engineer in the Pacific Northwest. While it may not be supported by scientific evidence it has proven to work satisfactorily.

Oil Specific Gravity

MSR generally uses 0.85 as an estimate for the hydrocarbon specific gravity. This is typical for diesel fuel and is based on some analyses of captured oil from working separators. Lubricating oil is somewhat denser than diesel fuel, but evidently more diesel fuel tends to leak than lubricating oils. Gasoline is so volatile that it evaporates almost immediately and does not enter into the drains. Thus it does not enter the oil-water separator.

With the flow rate, operating temperature, oil content, specific gravity and average droplet size (many of which will be estimated); it is possible to determine an appropriate size design for a separator. In addition, it is often necessary to consider several process situations to determine which is most stringent.

Typical small separator for fuel farm stormwater treatment

Vehicle Maintenance Operation Separators

Most of the maintenance facilities have some connection between the hydrocarbons that might leak or be spilled from vehicles and water that might be used for washing the floors. Consequently, oil-water separators are recommended for maintenance facilities.

Maintenance separators are utilized as either above ground or below ground separators. The above ground separators are usually made of metal whereas the below ground separators are usually made of concrete. The choice of separator design is often controlled by the requirements of the site, but all other things being equal, it is generally more cost-effective to utilize below ground precast concrete separators. Below ground systems are often retrofitted with the media installed in the frames. This is both for ease of installation and ease of later service. The captured oil is self-removing to the surface, but solid particles can accumulate in the media resulting in the need for physical removal.

Typical Below-Ground Installation Frame Type of Coalescing Media System

Existing Concrete Vault Refitted with Coalescing Media Frame System

Both of the systems shown above are installed at US Military installations in the US.

The quantity of the wastewater from an industrial or commercial facility may often be established by the flow of equipment such as pressure washers. The flow capacity of a standard pressure washer is approximately 4.5 US GPM (17 L/min), although there are much larger ones available. In the event that the major amount of flow results from the pressure washer, it is often possible to determine the flow from the nameplate of the pressure washer or the manufacturer's websites.

Sometimes the maximum flow rate will be the result of the use of one or more garden hoses for floor washing. A reasonable flow rate to use for designing under these circumstances is approximately 10 US GPM (37.8 L/min) per garden hose.

GENERAL DESIGN CONSIDERATIONS

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

1. Flow rate and flow 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. However, in some cases it may be necessary to estimate water flow quantities utilizing the Rational Formula or other means. 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.

Existing equipment, such as API 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.

It is necessary to ensure that adequate size piping is provided for downstream treated water removal to avoid flooding the separator. A downstream test point should be provided to allow for effluent testing.

Adequate means for recycling the oil should be provided (usually a recycling company). Careful records of removed and recycled oil should be kept to avoid possible future regulatory problems.

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

Inlet Flow (Influent) Conditions

Much of the performance of an oil-water separator depends on the influent conditions. Pumps, valves, restrictions in piping and other pressure-drop (shear) causing equipment will form a distribution of droplets with a smaller average droplet size than would otherwise be present in the flow stream. These smaller droplets are more difficult to separate because they rise more slowly. A separator designed to remove these smaller droplets must be significantly larger (and more expensive) than one designed for the larger average size droplets that would be present if no shear-causing equipment were utilized in the inlet stream.

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
5. Soaps or detergents NOT in use

Most separators are provided with an inlet elbow or tee inside the separator pointing downward. 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.

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

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. Likewise, a design utilizing media in a metal frame, as discussed above, is a good strategy if large quantities of solids are expected.

Outlet Flow (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.

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. In most underground systems, oil must be removed manually 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). In underground systems, captured oil holding tanks are usually not provided. This will avoid possible entanglement in the Underground Storage Tank Rules paperwork. In above ground systems, special oil holding tanks are often provided.

Removing the oil from the separators is not sufficient to protect the environment; it must also be recycled to ensure that it is disposed of properly. Current U.S. law holds 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.

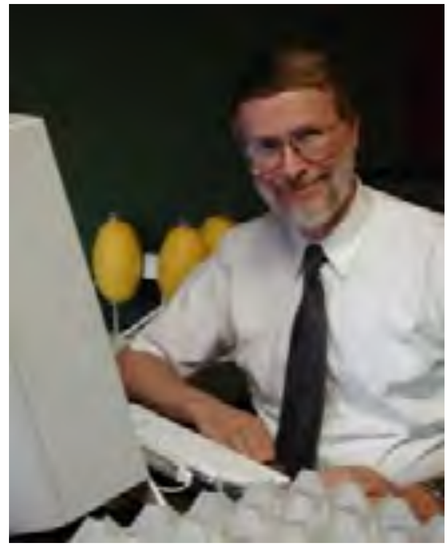
SUMMARY AND CONCLUSIONS

Environmental regulations are becoming more restrictive and requiring lower concentrations of hydrocarbons in effluent water. Some localities have much more stringent effluent standards than even the US EPA or other national bodies mandate.

Unfortunately, budgets for wastewater treatment are always very limited. Empty tank (API or API Type) systems are not adequate to ensure good treatment and it is essential to utilize a high-efficiency system to remove the oil.

Utilizing multiple angle coalescing plates, such as the Mohr Separations Research *HE-Media* design in concrete vaults or other systems, provides a cost-effective method of ensuring effluent water quality that meets or exceeds the requirements of federal, state, and local regulations. To ensure proper sizing, each system should be individually designed to meet all facility conditions and requirements. MSR green technology has proven sustainability and requires very little maintenance. Please contact MSR if you have questions or would like to discuss any aspect of this type design.

ABOUT THE AUTHOR



MSR was founded in 2001 by Kirby S. Mohr, a degreed engineer specializing in the filtration and separation of liquids. Kirby holds degrees in Chemical Engineering and Environmental Engineering from Iowa State University and Oklahoma State University, respectively, and is a Registered Professional Engineer in Texas. He has more than forty years of experience in engineering, with the last thirty specializing in separation and filtration.

Kirby is a Vietnam Veteran. He is also a member of the Water Environment Federation, the Society of American Military Engineers, the American Rainwater Catchment Systems Association, AmericanRivers.org, the US Navy Supply School Alumni Association and others. He has been a member of the ASTM and ULC committees for preparing test standards for oil water separators.

Since the company founding, we have completed projects in the Electric Utility, Oil Refining and Production, Chemical Manufacture, Stormwater Processing, Transportation, and Vehicle Maintenance industries. Our projects are very diverse, ranging from the design of oil-water separators for US and Canadian fire training schools, to two very large separators for a large Canadian electric power generation facility, and four of the world's largest for a US petroleum refinery. Our systems have been installed from coast to coast and from Texas to near the Arctic Circle as well as international locations, including Europe and South America.

REFERENCES

American Petroleum Institute (API), Bulletin 421, 1990.

Bennett, E.R., Linstedt, K.D., Nilsgard, V., Battaglia, G.M., Pontius, F.W., "Urban Snowmelt -Characteristics and Treatment", Journal, WPCF, Vol. 53, No. 1, January, 1981.

Buchholz, G.M., Defining the Urban Stormwater Runoff Problem, a report prepared for the National League of Cities and The National Realty Committee, Montgomery Watson Co., Walnut Creek, CA, 1994.

Eaganhouse, R.P., and Kaplan, I.R., "Extractable Organic Matter in Urban Stormwater Runoff," Environmental Science and Technology, Vol. 15, No. 3, March, 1981.

Findley. Roger W., and Farber, Daniel A., Environmental Law in a Nutshell, St. Paul, MN, West Publishing Co., 1992, pp. 132-152.

Gamble, K.G., "Lab test results for Metals and 13 Priority Pollutants (soil)", a report compiled for Getoechnical Marine by Paul R. McGinnes and Associates Consulting Laboratories, Inc., West Palm Beach, FL, 1994.

Government of Canada. 1978. Canadian Fisheries Act. Web Page, accessed Mar. 20, 2013.

Hill, R. (n.d.). *Bacterial Activity in Harvested Rain Water* (pp. 1–8). Penn Bucks, UK.

Hoffman, E.J., Latimer, J.S., Mills, G.L., and Quinn, J.G., "Petroleum Hydrocarbons in Urban Runoff from a Commercial Land Use Area," Journal, WPCF, Vol. 54, No. 11, November, 1982.

Hunter, J.V., Sabatino, T, Gomperts, R., and MacKenzie, M.J., 'Contribution of Urban Runoff to Hydrocarbon Pollution", Journal of the Water Pollution Control Federation, Volume 51, Number 8, August, 1979, pp. 2139- 2138.

Leisenring, M., Clary, J., Lawler, K., & Hobson, P. (2011). International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary : Solids (TSS TDS and Turbidity) (pp. 1–28).

Livingston, E.H., "The Use of Wetlands for Urban Stormwater Management", In Design of Urban Runoff Quality Controls, Ed. Roesner, L.A., Urbonas, B., and Sonnen, M.B., ASCE, New York, NY, 1989.

McDowell, R.A., "Report of Testing of CPS-48 Separator With Used Lubricating Oil", Facet International, Inc. 1995.

Perry, John H. et al, “Chemical Engineer’s Handbook”, McGraw-Hill Book Company, 1963.

Romano, Fred, "Oil and Water Don't Mix: The Application of Oil-Water Separation Technologies in Stormwater Quality Management", Office of Water Quality, Municipality of Metropolitan Seattle, WA, 1990.

Snoeyink, V., and Jenkins, D., Water Chemistry John Wiley & Sons, New York, 1980.