HOW OIL-WATER SEPARATORS WORK AND HOW TO USE THEM

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INTRODUCTION

When it is necessary to remove oil from water, coalescing plate module type oil-water separators are often a good solution because they remove the oil using only gravity as the motive force. The separator modules are permanent and require little to no maintenance, no absorbents or other consumable items (such as filter cartridges) are required, and the oil that is separated is often recyclable. No pumping or other utility costs are usually required (although pumped systems can be designed if this is required by the site conditions). They can be designed to function under a great range of operating conditions and handle input oil contents up to 100%. Separator systems are often located underground in order to minimize the waste of valuable space on the surface and to take advantage of the opportunity to allow for an inlet flow by gravity. Gravity inlet flow is preferred because of the greater average droplet size, and therefore, better removal.

Because oil-water separators operate using gravity as the operating principle, their design is more difficult and requires more expertise than the design of filtration or other systems that operate under pressure. The ongoing benefits of low operating and low maintenance costs and the sale of recyclable oil, usually outweigh the slight added expense of the initial designs. No absorbents are required, so disposal costs are limited only to the disposal of the recovered oil.

The following contains some general information on how oil-water separators operate and provides specific information on coalescing plate module type separators as well as constraints and design suggestions. Please contact MSR so we can offer further suggestions or information.

GENERAL DISCUSSION AND THEORY OF OIL-WATER SEPARATION

In 1845, an English mathematician named George Stokes first described the physical relationship that governs the settling solid particles in a liquid (Stokes' Law, 1845). This same relationship also governs the rising of light liquid droplets within a different, heavier liquid. This function, simply stated is:

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

Where:

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

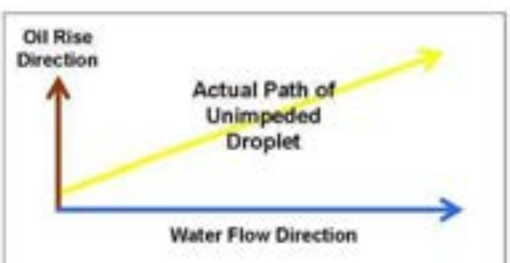
A negative velocity is referred to as the particle (or droplet) rise velocity. Assumptions Stokes made in this calculation are:

1) Particles are spherical
2) Particles are the same size
3) Flow is laminar, both horizontally and vertically. Laminar flow in this context means flowing gently, smoothly, and without turbulence.

From the above, it can be seen that the variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid and the particle, and the particle size.

The rise rate of oil droplets is also governed by Stokes' Law. If the droplet size, specific gravity, and viscosity of the continuous liquid are known, the rise rate can be calculated.

To calculate the size of an empty vessel gravity separator, it is first necessary to calculate by the use of Stokes' 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 (residence time) must be provided in the separator so that an oil droplet entering the separator, at the bottom of the inlet end of the separator, has time to rise to the surface before the water carrying the droplet exits the opposite end of the separator.



RISE PATH OF A TYPICAL OIL DROPLET

Calculation of the rise rate by this method is a gross simplification of actual field conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Furthermore, inevitable turbulence within a separator makes an orderly rise of very small droplets impossible.

Droplets will rise following Stokes' Law as long as laminar flow conditions prevail. When the particle size exceeds that which causes a rise rate greater than the velocity of laminar flow, flow around them (as they rise) begins to be turbulent. Particles of this size and larger do not rise as rapidly as would be expected from calculations based on Stokes' Law because of the hydrodynamic drag. However, they do rise very quickly in relationship to smaller droplets, and so, are removed by a properly designed separator.

Very small particles, such as those of 8 microns (micrometers) and less in diameter, do not rise according to Stokes' Law (or hardly at all) because the random motion of the molecules of the water is sufficient to overcome the force of gravity. As a result, they move in random directions. This random motion is known as Brownian Motion. Fortunately, the volume of a droplet decreases according to the cube of the diameter, so these very small droplets tend to contain very little oil by volume, and unless there are large, large quantities of very small droplets (such as would be created by using a centrifugal pump to pump the water), they contain negligible amounts of oil.

When the droplets coalesce, they do not form flocs as the solid particles can, but coalesce into 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. This is convenient for a separator designer because it is required by Stokes' Law.

Several types of separators that utilize this principle have been designed, including API Separators, Corrugated Plate Interceptors (CPI) and others. In general, the most efficient and predictable of these systems are the Coalescing Plate Module type.

An extensive discussion of API and other separation systems is provided in the technical paper "A New Kind of Oil-Water Separator for Better Water Quality Management" and is available on request from the Publications list on the website. For reasons of brevity, only the Coalescing Plate Module type design is detailed in this discussion.

Coalescing Plate Module Separator Design

It is very difficult to be sure of maintaining laminar flow (as required by Stokes' Law) in large empty-tank separators because of the turbulence problem noted above. For this reason, coalescing modules are used to ensure laminar flow, and therefore, a system that behaves according to Stokes' Law.

The Stokes' Law calculation is accurate for oil droplet 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 problem with performing this calculation is obtaining the following required data:

1. What are the respective specific gravities of the liquids?
2. What is the particle size?
3. What is viscosity of the water?

The design of separators can require design over a wide variety of temperatures (and therefore water viscosities) to account for summer and winter conditions, as well as possible process upsets, so several water viscosities may be considered during design. The specific gravities are usually known or can be readily estimated. The viscosity of the water is readily obtained from literature data. The oil droplet *size*, however, is much more difficult to determine.

The 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.

If the droplet size is not known, or a large range of droplet sizes is present (the normal situation), it is necessary to make some estimates of the droplet sizes in order to determine the rise rates of the droplets, and therefore, the size separator required. These estimates are usually made based on previous experience with separation systems.

A separator is therefore presented with a flow stream containing a mixture of various droplet sizes of hydrocarbons in water. Because many different droplet sizes are present, a simple Stokes' Law removal calculation will not provide an accurate removal efficiency calculation. A reasonable way to treat the problem of removal, to meet a specific maximum oil concentration requirement, is in a statistical manner. If we can show that fewer particles will pass through a separator than are required to cause 15 ppm in the effluent (or other requirement if a lower effluent is required), we can confidently predict that the separator will meet the effluent standards necessary under the law.

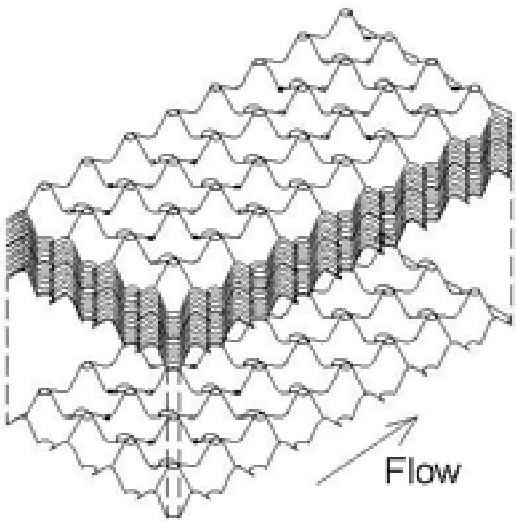
MSR utilizes a proprietary computer program to do the statistical determination of the oil droplet removal, and therefore, the effluent oil content. Careful use of this tool allows MSR to ensure that the effluent will not exceed regulatory requirements under different design conditions. A copy of a typical calculation is provided in the appendix.

Oil should not be present in water exiting an industrial or commercial facility in quantities large enough to cause oil sheens or even in very small quantities. In the US, the Clean Water Act (CWA) requires that there be "no sheen" but does not define what causes a sheen. "No sheen" is often taken to mean 15 mg/l (ppm) or less. Many jurisdictions, including King County, Washington (Seattle), have enacted standards allowing discharge oil levels considerably less than the EPA limit of 15 ppm oil and grease in water discharged (Romano 1990). Some jurisdictions, such as the Canada Fisheries Department (Government of Canada 1978) allow even less oil and grease in effluent water.

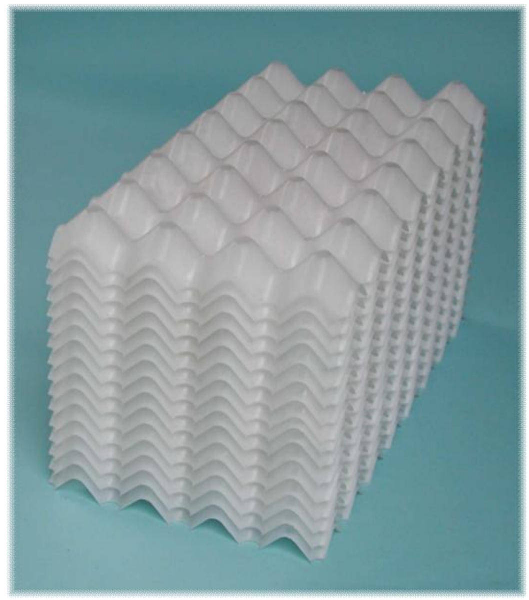
MSR Multiple Angle Plate Module Separator Features

Multiple angle plate separators were developed to remove the oil in an effective manner, while still being resistant to plugging by solid particles.

These separator plates are corrugated in both directions, making a sort of "egg-carton" shape. Spacers are built into the plates and constructed so that two spacings (nominal 8 and 16 mm) can conveniently be made. Narrower spacings are more efficient and wider spacings are more resistant to plugging by any solids that might be present. A drawing of the separator modules is included in the appendix and a sketch and photo are provided below.



MSR Typical Plate Module



The flow in a module such as this is along the long axis of the module. Oil droplets rise up and meet the undersides of the plates where they are separated, and solids particles fall onto the top surfaces of the plates and are directed to the bottom of the separator.

There is a maximum flow rate per volume of media that will still be within the laminar flow requirements of Stokes' Law. To meet this flow limit per module, MSR designs systems using multiple modules. The modules are placed side by side and stacked as high as necessary to allow for the flow rate, and at the same time, maintain laminar flow. If the process simulation program indicates that a single row of coalescing media will not be sufficient to provide effluent quality that meets the requirements, multiple rows of media can be provided. Systems have been successfully designed of up to 20,000 US gallons per minute (4550 cubic meters per hour). The photos below show a concrete vault for underground use and an above-ground steel unit with four rows of media currently installed at an Illinois tire manufacturing plant.

Concrete Vault at OEM   Tire Company Steel Separator

Advantages of the MSR system are:

a) The stacked plates allow for design of the system within a laminar flow regime. Only a laminar flow regime allows for true Stokes' Law behavior of the droplets, and therefore, predictability of droplet capture and effluent quality.

b) The plates in the modules 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 MSR systems, the solids only have to slide a few millimeters before encountering one of a multitude of solids removal holes. The solids drop directly to the bottom of the separator through the holes.

c) The double corrugations provide surfaces that slope at a forty-five (45) degree angle or more in all directions, so that coalesced oil can migrate easily upward.

d) The coalescing plates are arranged in modules so that they can easily be stacked in a vault, tank, or above ground system.

Most large units are designed utilizing plate modules installed in underground 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.

CONSIDERATIONS FOR THE 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 systems. Among these are:

1. Flow rate and conditions
2. Degree of separation required - effluent quality
3. Amount of oil in the inlet water
4. Existing equipment - such as concrete vaults or pumps

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, and other conditions may be easily determined. For stormwater applications, 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 sanitary sewer or industrial treatment plant, allowable effluent oil content may be negotiable.

The amount of oil in the inlet 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.

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.

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. Sometimes it may be necessary to replace existing equipment, such as centrifugal pumps (which produce difficult- to-separate emulsions), with equipment more suitable for use with oil-water separators. Many times it may be necessary to substitute quick-break detergents for conventional detergents that can also cause emulsions. The US Army Corps of Engineers has made a study of these quick-break detergents and MSR will be glad to send a copy (US Army Corps of Engineers, 2007). If it is at all possible, detergents and soaps should be avoided and cleaning with only hot water or steam should be used.

It is necessary to ensure that adequately sized piping is provided for downstream treated water removal in order to avoid flooding the separator and perhaps filling the oil reservoir with water. A downstream sample point may 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 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 because equipment or conditions that cause small droplet sizes in the influent to the separator will cause requirements for a larger separator to accommodate the additional time required for the smaller droplets to coalesce.

Conditions that cause 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)
5. Emulsifying chemical agents (soaps and detergents)

Emulsifying agents, such as soaps and detergents, greatly contribute to small droplet sizes in addition to disarming coalescing plates and discouraging coalescing.

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

Note: 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 avoiding disturbances of the surface oil and possible re-entrainment of some of the already separated oil.

Gravity flow conditions are not often obtained except in sanitary sewer systems. For stormwater, or some process water applications, a positive displacement pump (such as a progressive cavity type pump) may be used because they provide minimum disturbance of the fluid. The best choice, if gravity flow is not available, is a progressive cavity-type pump. Inlet piping should be as smooth as possible to avoid turbulence caused by pipe roughness. Smooth PVC is preferred as opposed rough concrete.

Sometimes anti-emulsion 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. Plant operators have a tendency to believe that if a small amount of anti-emulsion chemical is good, then a really large amount is even better. It is necessary to provide sufficient operator education to avoid this problem and best to avoid the use of such chemicals.

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

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. Manholes overflowing during a heavy rainstorm will surely cause any oil caught in them 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.

Oil must be removed from the separator on a regular basis, preferably continuously. If not removed in a timely manner, this oil may fill the separator, blinding the media and causing high effluent oil contents. It may eventually become re-entrained at the next rainfall event and reintroduced into the environment.

Removing the oil from the separators is not enough to protect the environment; it must also be recycled to ensure that it is not merely treated as a waste and avoid possible problems elsewhere from improper disposal. Current law can hold the owner of the oil-water separator responsible if the oil is not properly disposed of, even if the owner had paid for proper disposal.

CONCLUSION

Removal of unwanted oil from water, especially stormwater, continues to be an environmental and economical problem. The use of coalescing plate module type oil-water separators has a number of benefits for both economic and environmental perspectives:

- Economical and reliable operations
- Low operating and maintenance costs
- Gravity operated, so no utilities required
- Recyclable oil recovered
- Can take little above ground space
- High efficiency and ability to meet environmental regulations
- Predictable performance
- Ability to handle surges of oil or water

If it is necessary to remove oil from water, either from stormwater or industrial streams, coalescing plate module type separators are often a very good long- term choice. Please contact us for more suggestions or additional information.

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APPENDIX

Typical Separation Calculation

Mohr Separations Research, Inc.

Coalescing Plate Analysis
Rev 2: August 2010

Customer:	Typical	MSR Ref:	Q13 typical
Customer Ref:	Stormwater	Date	03-Jan-13

Continuous Fluid		Immiscible Phase	
Fluid:	Water	Material:	Oil
Flow Rate: US gpm =	450		
Temperature, Deg. F.=	32	Specific Gravity:	0.83
Viscosity Used, Cp =	1.792	Measured at Deg. F.	60
Specific Gravity Used =	1.001	Specific Gravity at Temp.=	0.843
Flow Rate, m3 / hour =	102.20	Log Normal Distribution	
Temperature, Deg. C =	0.0	Concentration, mg/l	100
		Mean size, microns	120
		Standard Deviation	2

Plate Pack Configuration

Packs Wide =	5	Number of Rows	1
Total Width, inches =	59.1	Flow Path, Inches =	23.6
Total Width, mm =	1500	FLow Path, mm	600
Height, inches =	53.5	Plates / Stack foot =	30
Height, mm =	1359		

Plates / Fluid Characteristics		Effluent Characteristics		
Flow Rate, gpm	450.0			
Stack Feet provided	22.29			Oil
gpm / stack foot	20.19	Effluent mg/l		9.8
Frontal Area, ft2	21.941			
Plate Volume, ft3	43.190	Percent Reduction		90.2
gpm/ft2 frontal area	20.510			
Velocity in plates, ft/min	3.425	Size 100% collected, microns		68.8
Res. time in plates, min	0.584			
Plates / stack foot	30.0	Collection rate, lbs / hour		20.33
Plate spacing nominal	8 mm NOM.		Gallons / hour	2.89
Plate Surface area, ft2	3887			
Pressure drop, in H2O	0.06	Collection rate, kg/hour		9.22
Reynolds No. in plates	102.4		l / hour	10.95
Percent of Laminar Limit	5.1			