DESIGN, TESTING, AND OPERATING EXPERIENCE OF A SALTWATER DISPOSAL SYSTEM OIL-WATER SEPARATOR

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Abstract:

Environmental regulation of oil in salt water disposal from oil and gas operations are becoming more stringent and the high value of crude oil makes recovery of any residual oil in the produced water attractive. Most of the current methods used for recovery are older designs and not very efficient, so a new and more efficient system would be useful in the industry.

A test was performed using a coalescing media test system at a disposal well site in West Texas and the oil removal efficiency was very good - enough to suggest the commercial value of a large separation system. A full size system was designed and constructed using a frac tank as the basic structure and utilized coalescing media to perform the separation.

The following paper will include information on the initial testing, design of the system, and field operations and performance.

Keywords:

Oil, water, crude. oil-water separator, separation, saltwater disposal

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Introduction:

Many separation devices currently used in the oil production industry are similar or identical to those used a hundred years ago. The technology that was adequate for production at that time is no longer adequate, either for environmental purposes or to recover the last amount of oil present, in produced water that is to be injected through a saltwater disposal system. Many types of separation equipment, including horizontal separators and gunbarrels, are capable of removing most of the oil from the saltwater, but are not efficient at removing the last traces of oil.

The residual oil in the water downstream of the old-style separators can be as much as 1% to 3%. This amount of oil, while not representing the bulk of the production, can still be of substantial value.

Because of this interest in removing virtually all of the oil, Mohr Separations Research, Inc. (MSR) was contacted by a consultant for a major West Texas production company about a more efficient separator design.

The customer wanted to improve separation for:

1. Resource recovery – they can sell any oil that is captured by the system
2. Avoiding primary plugging of downhole areas by oil
3. Avoiding secondary plugging of downhole areas by bacterial growth

This oil, which is present in the saltwater, will also cause problems in the disposal well if it is allowed to be pumped down the well. The problems which can be caused are primarily plugging problems, firstly because of the oil itself, and secondly because of bacterial growth, which can happen at the underground injection point.

It was therefore desired to have a more efficient design which would remove virtually all of the oil from the water, firstly, for profitability, and secondly, for avoiding plugging and subsequent maintenance problems downhole.

In the customer's West Texas and New Mexico facilities, they had substantial amounts of light crude oil with a specific gravity of approximately 0.82, contained in a large amount of water, up to 36,000 barrels per day (1050 US GPM). They also had a warm water temperature of about 100 °F.

Origin of the Water:

Common separations systems used in the oilfield include gunbarrel separators and horizontal separators. The gunbarrel separator systems, as illustrated in *Figure 1* below, are simple gravity systems, where the oil, gas and water mixture comes to a pre-separation system and the gas is supposed to mostly separate out in the pre-separation system and join the gas, which eventually separates out of the oil-water mixture at the top of the gunbarrel. The oil and water mixture flows into the distributor, near the bottom of the separator, where the oil droplets are supposed to collect under the umbrella style distributor and weep upward into the oil layer, and water droplets are supposed to coalesce and come downward. Any water drops entrained in the rising oil will migrate into the oil layer above the water layer, and from there, must fall back down through the oil layer to rejoin the water.

These systems are simple, easy to operate, and tolerant of solids, but the flow pattern and lack of properly designed internals keeps them from being very efficient at removing smaller droplet sizes. This is because the design of the gunbarrel does not meet the laminar flow criteria for Stokes' law, which is further discussed below.

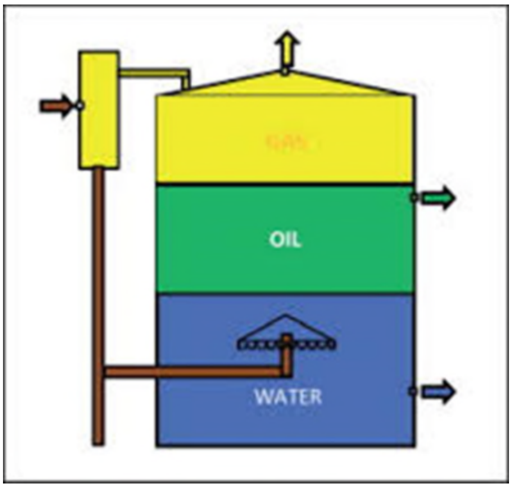

Figure 1: Typical Gunbarrel Separator

Another common separator design, often used in the oilfield, is a three-phase horizontal separator, as illustrated in *Figure 2* below. In this system, the oil and water and gas mixture enters through the inlet nozzle, near the top, and the gas immediately disengages, prior to the inlet deflector, and proceeds along the top of the separator to the opposite end, where there may or may not be a separate gas outlet. The gas may also be combined with the liquid in the outlet. As shown in the figure, a water layer is maintained below the oil layer.

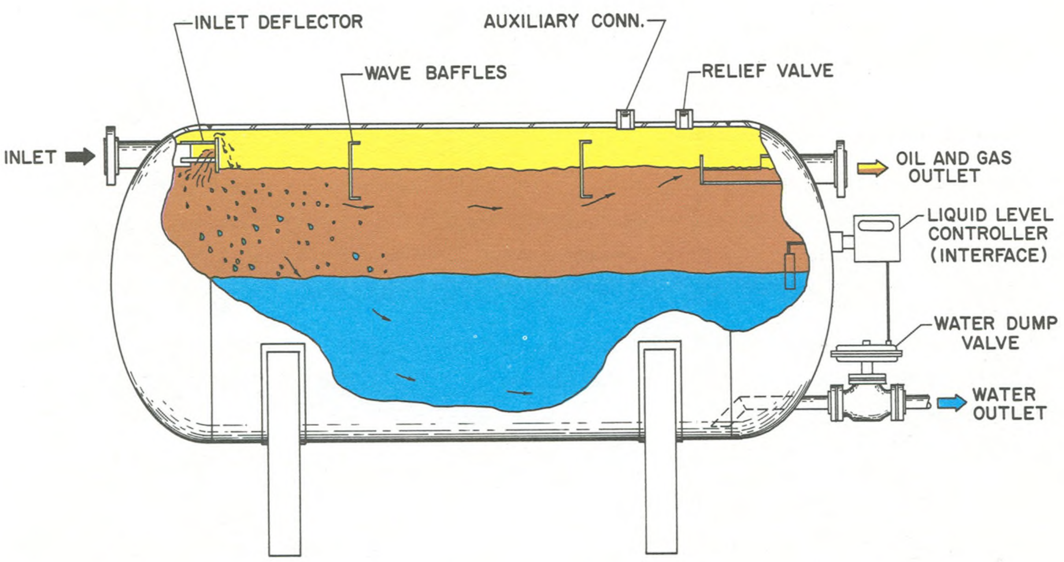

Figure 2: Typical Three-Phase Horizontal Separator

Problems associated with this design are that all of the water in the inlet must pass through the oil layer in order to get to the water layer at the bottom of the separator. This causes entrained oil droplets to be carried downward into the water layer; likewise, there should be a movement of entrained water drops through the oil layer, down to the water layer. Neither of these actions happens very efficiently because the systems do not meet the requirements for Stokes' law and because they are designed so that the droplets of one phase must pass through another phase.

Separation by Gravity (Stokes' Law):

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 (Perry, 1963):

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

Where:

Vp = particle rising or settling velocity, cm/sec
G = gravitational constant, 980 cm/sec^2
μ = absolute viscosity of continuous fluid, poise
dp = density of particle (or droplet), gm/cm^2
dc = 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 include:

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 density of the droplets, the viscosity of the continuous phase (temperature), specific gravity difference between the continuous liquid and the particle, and the average droplet size (square function).

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.

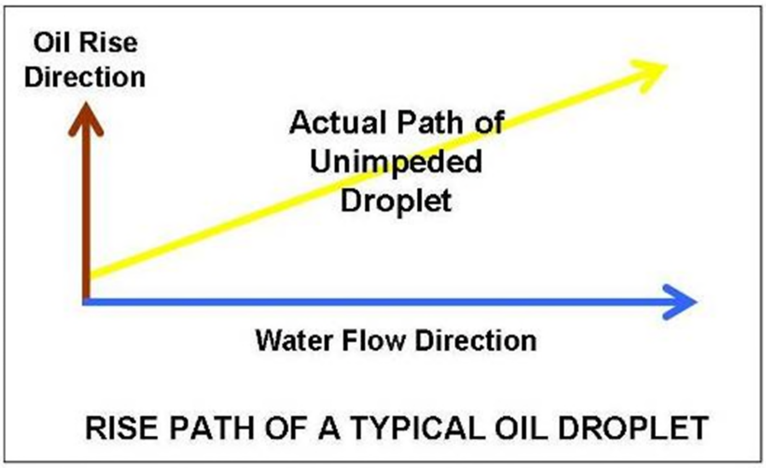

Figure 3: Rise Path of a Typical Droplet

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.

Initial Testing:

MSR is a designer and manufacturer of coalescing plate separators for use in many oil removal applications. The possible installation was reviewed to determine if it was a likely candidate for the use of coalescing media, and the relatively low density crude oil to be removed indicated it was likely that the application would work well using MSR’s coalescing plate technology. An initial flow test utilizing a small MSR-11 type separator was arranged.

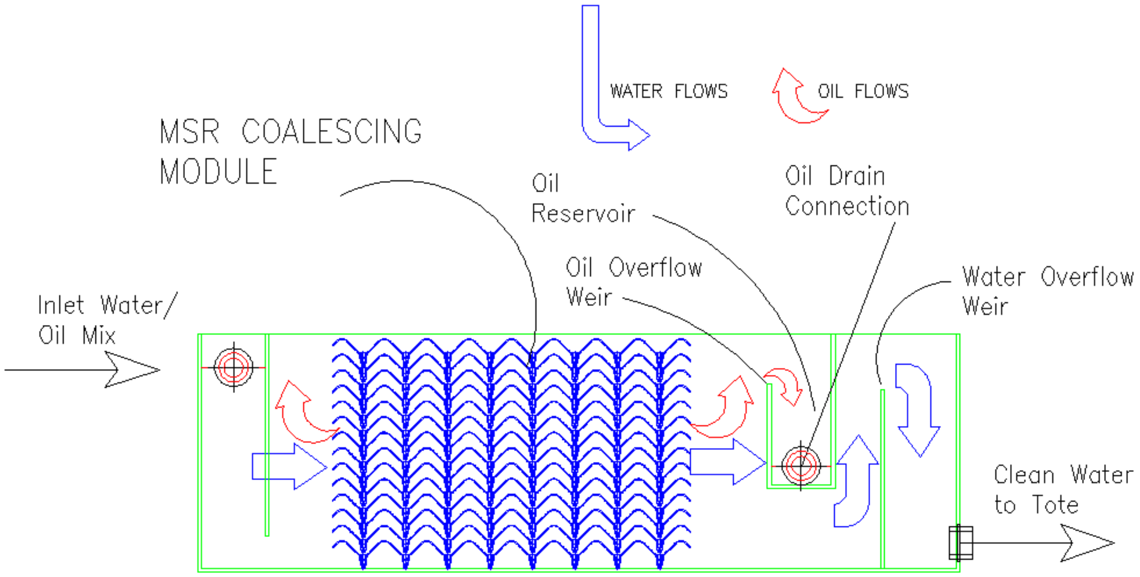

Figure 4: MSR-11 Test Unit

The MSR-11 pilot testing unit was installed at a customer owned facility in eastern New Mexico. Flow was by gravity from the bottom of the large storage tank through the stainless steel separator and the outlet water was directed to a tote. This arrangement was made so that testing could be done without disturbing operations of the plant. The photo below shows the separator mounted on a metal stand and the inlet hose may be seen from the tank, over the berm to the separator and the cleaned outlet water flow was then directed to the tote.

Figure 5: Pilot Test Setup

Initial visual comparison between the inlet and outlet samples indicated good separation. In *Figure 6* below, the inlet samples are in jars one and three from the left and the corresponding outlet samples are in jars two and four from the left.

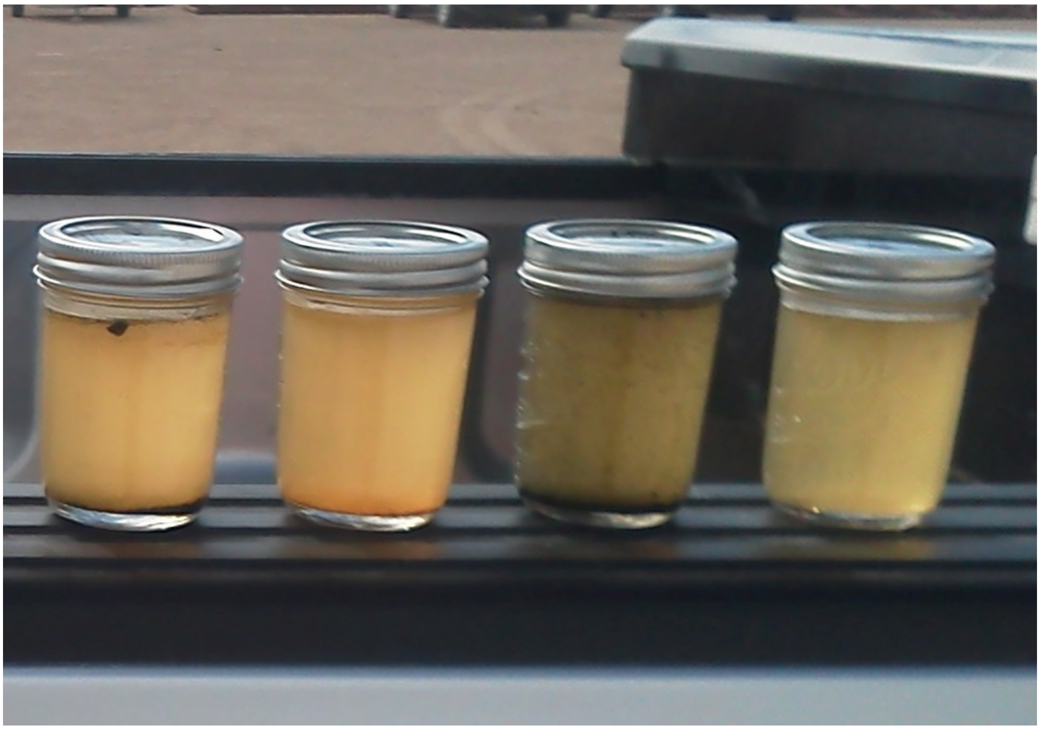

Figure 6: Pilot Testing Typical Samples

The pilot testing program was conducted in September 2013. The test flow rate varied somewhat because of the test system design; average flow rate was approximately 1 US GPM. The separator operating temperature was approximately 100 °F. Inlet sample concentrations varied from 77 mg/L to 128 mg/L, and the outlet concentrations varied from 21 mg/L to 28 mg/L. These were lower concentrations than initially expected by the customer, and it is believed that this was at least partly due to the sample flow being taken from a location near the bottom of the tank. Because the water is from various sources, it is likely that some truckloads of water will contain substantially more oil than was found during this test.

The average oil droplet size in the flow stream was back calculated based on the information provided by the test results. For the relatively low inlet oil concentrations used in that test program, the average oil droplet size was found to be about 15 µ. There are of course many larger droplets than 15 µ and some smaller ones. At higher concentrations, the average droplet size would be expected to be higher.

Full Scale Unit Design:

Preliminary calculations and discussions with the customer indicated that a system installed in a 500 barrel frac tank would be convenient for processing approximately 36,000 barrels per day of water (1050 US GPM).

This size tank lends itself to a coalescing system consisting of one or more rows of the MSR modules, seven modules wide and with a water height within the modules of 71.5 inches.

After deciding on the width and height of the coalescing system, MSR considered several possibilities with multiple rows of coalescing media. It was determined that the maximum amount of media that might possibly be required would be seven rows. The design of the system was therefore for any amount of media between one and seven rows. This design gives the flexibility of being able to use the same unit for substantially different applications by simply adding or subtracting media as required.

The particular customer application that the initial unit was designed for conveniently fit in a system with three rows of media. The design of the initial unit that was constructed is shown in the sectional drawing shown in *Figure 7* below.

The initial unit was sized for an effluent quality of 50 mg/L or less with a 0.82 specific gravity West Texas crude oil and an effluent quality of 50 mg/L or less utilizing three rows of media. Additional rows can be added, if necessary, for larger flows or lower effluents.

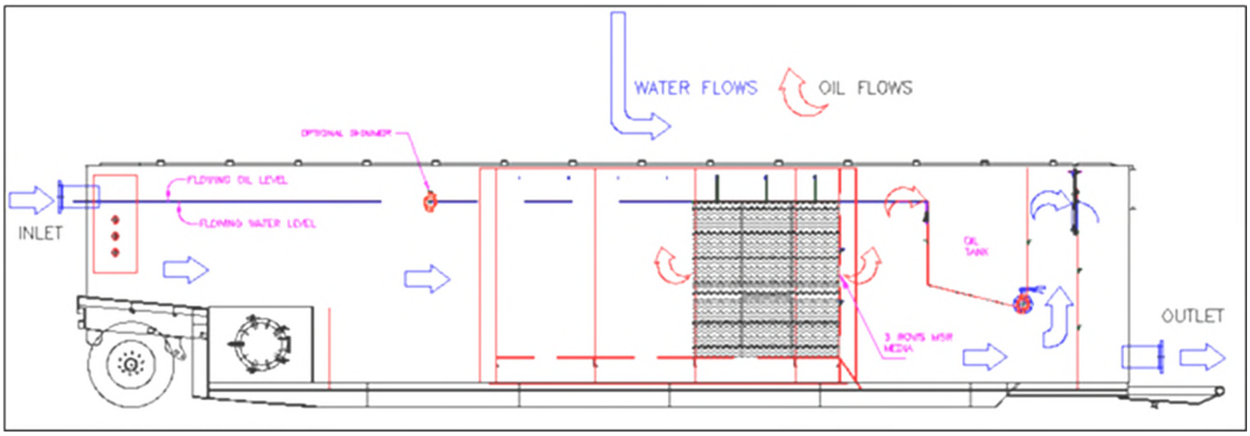

Figure 7: Full-Scale Unit Section

Because of the likelihood of some solids being present in the inlet, even though the bulk solids will have been removed upstream in other equipment, a solids trough was provided under the media area with holes that correspond to the holes in the valleys of the media. Solid particles fall on the top side of the media in the same way that oil droplets rise up and meet the underside of the media. The oil droplets are directed to the surface by the oil ports in the peaks of the coalescing plates and solid particles are directed downward to the solids sump, through the solids dump holes in the valleys of the plates.

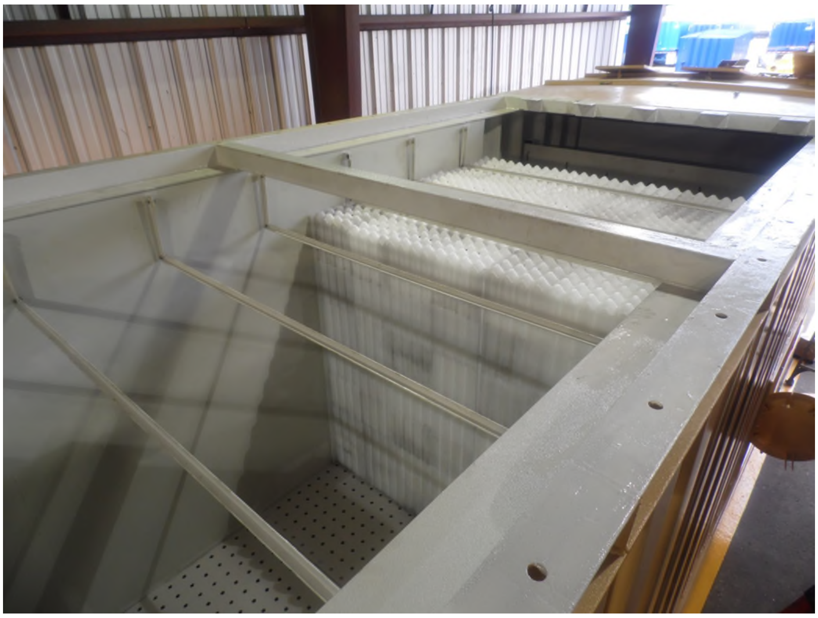

Figure 8: Full-Scale Unit Under Construction

Please note, plate hold downs are provided for all seven rows, even though only three rows are installed. Solids dump holes in the support plate, over the solids trough, may be seen above in the lower left of *Figure 8*. A large hatch has been constructed in the ceiling of the tank for use during both the original installation and subsequent maintenance. Special adjustable water overflow and oil overflow weirs, which can be adjusted to compensate for substantially off level conditions, have been provided.

Field Operations:

The first, of a series of three units, was put into operation in July 2014. Operations to date have been very satisfactory.

Figure 9A: Separator Installation, New Mexico

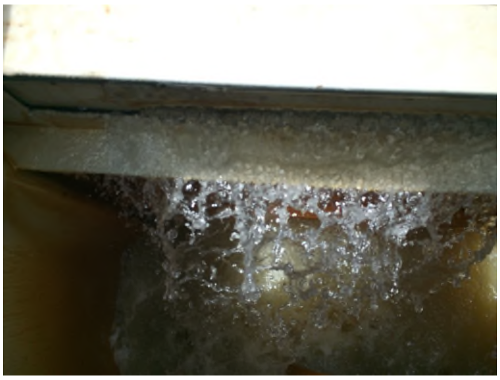

Figure 9B: Clean Water Overflow

Figures 9A and 9B above, illustrate the initial commercial operations of this system. In *Figure 9A*, the large outlet piping and smaller oil outlet piping may be seen at the right of the photo. In *Figure 9B*, the cleaned water is shown overflowing the outlet weir and into the outlet chamber.

Limited testing was conducted on the operation of the separator, which has proven to be very successful. *Table 1* below represents the test results.

Table 1: Test Results, Full-Scale Unit	
Inlet hydrocarbon concentration	Outlet hydrocarbon concentration
90 mg/L	13 mg/L
85 mg/L	14 mg/L
119 mg/L	7 mg/L
Unit in successful commercial operation since July 2014	

Selection of Equipment:

The Dragon/MSR separator is designed to be very versatile and can process up to about 36,000 barrels per day of saltwater. In general, at lower flow rates, effluent quality will be better than design. This design can be used in many circumstances with different oils and flow rates.

The information necessary for MSR to determine the appropriate design for a given set of requirements is:

- Operating conditions, including
  - flow rate (maximum instantaneous flow rate)
  - operating temperature
  - oil specific gravity or API gravity
  - saltwater density
  - expected inlet oil content
  - if possible, information about the inlet flows such as pumps or chokes
- Degree of separation required – the effluent quality desired
- Any special issues to be considered such as possible differences in oil specific gravity

With this information, MSR can specify the appropriate size separator, or if the flow rate is sufficiently large, as to justify the use of a frac tank separator, such as described in this paper, the number of rows of media to be installed.

Other Applications:

This technology can be used in virtually any situation where unwanted oil is present in water streams:

- Oil refinery API separators/outfalls

- Tank farms for rainwater runoff water
- Replace or supplement gunbarrels or other production separators

Green Technology:

Coalescing plate separators are a very sustainable and very green technology with the following advantages:

- Gravity operated
- Offers high-efficiency predictable oil removal
- Can be designed for whatever maximum effluent oil content is required
- Much smaller than other separators for the same flow rate
- Coalescing plates are not consumed and can last for many years
- The recovered oil is not contaminated with flocculants or other chemicals and can readily be sold

Summary and Conclusions:

Coalescing plate separators, such as the Dragon/MSR design, can be used cost effectively to recover oil that would otherwise be lost, reduce plugging of disposal well strata by oil, reduce plugging of well strata by bacterial growth that is fed by the oil, improve operations and reduce maintenance.

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