DO API AND API TYPE SEPARATORS WORK?
A COMPARISON OF THE DESIGN AND PERFORMANCE OF API TYPE SEPARATORS WITH COALESCING PLATE SEPARATORS

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ABSTRACT: Environmental regulation of oil in water discharges is increasingly becoming more stringent. Many localities now require oil content of water discharges to be limited to less than 10 mg/l. Various types of oil-water removal systems are available. These systems include “API type separators”. The benefits and drawbacks of API separators are presented and discussed in this paper.

Keywords: Oil, Water, Oil-Water Separator, API separator, API type separator, API performance

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BACKGROUND AND INTRODUCTION

For centuries, humanity has known that oil and water do not mix - at least not very well. However, what ancient man did not realize is that oil and water will mix under certain conditions and emulsions will form that can be very difficult to separate.

Petroleum products came into general use in the late 19th century due to the replacement of well oil with kerosene. Kerosene was originally known as coal oil because it was manufactured by the destructive distillation of coal. It was patented in 1854 by Dr. Gessner of Williamsburgh, New York (Scientific American 1854). It was subsequently made in bulk by distillation of crude oil.

After automobiles became common in the early part of the 20th century, oil refining grew from almost a cottage industry to a major industrial part of the U.S. economy. As oil refineries grew, the quantity of effluent water entering the rivers and streams increased as well. Because most of the water in the effluent is the result of the processing of the hydrocarbons, much of it contained various hydrocarbons. After World War II, the quantity of water exiting the refinery and therefore the quantity of hydrocarbons became a substantial environmental nuisance and in addition it became obvious that a great deal of money in the form of hydrocarbons was being wasted.

The American Petroleum Institute (API), an industry society, decided it was necessary to have a method of removing the oil from the effluent water. This would not only alleviate the nuisance but also capture a great deal of hydrocarbons which could be recycled through the refinery.

API SEPARATORS:

In 1947, the API commissioned a study from the University of Wisconsin to determine the design method that could be used to design separators for removing the oil from water in refinery effluent water. The purpose of this design method was primarily for resource recovery although it also helped with mitigating the nuisance effect of oil exiting the refineries and entering streams and lakes.

This design method has been revised several times, notably in 1979 and 1990.

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 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 1 below adapted from API (American Petroleum Institute 1990).

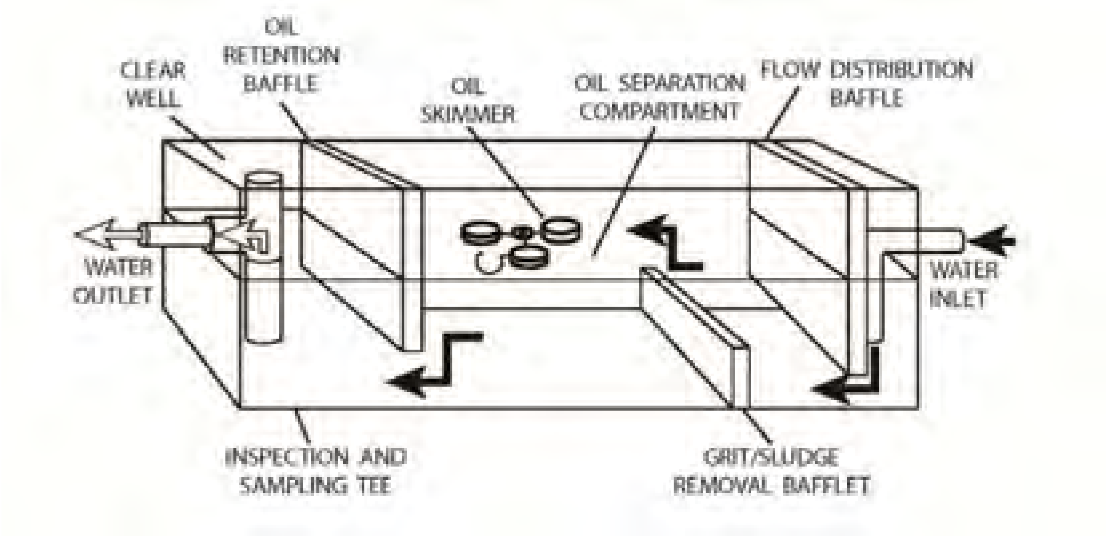

Figure 1: API Separator

Systems are also sold as “API type separators”, which commonly means that they have the same general baffle arrangement as a regular API separator, but do not conform to the design criteria 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 as discussed below.

SEPARATION BY GRAVITY:

Separation of oil and water is different than 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 as oil does.

Settling of Solid Particles

The settling of solid particles in a separation device, is governed by Stokes' Law. In an API separator, this is the working principle as well, but the droplets rise instead of fall. This function, simply stated is (Perry 1984):

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

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's (or droplet's) 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 rise 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 solids. They do not perfectly obey Stokes' Law because of their particle shape.

Rising of Oil Droplets

The rise rate of oil droplets is also governed by Stokes' 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 (with some assumptions required).

To calculate the size of an empty-vessel API or API type 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 must be provided in the separator so that an 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. This is graphically illustrated in Figure 2 below.

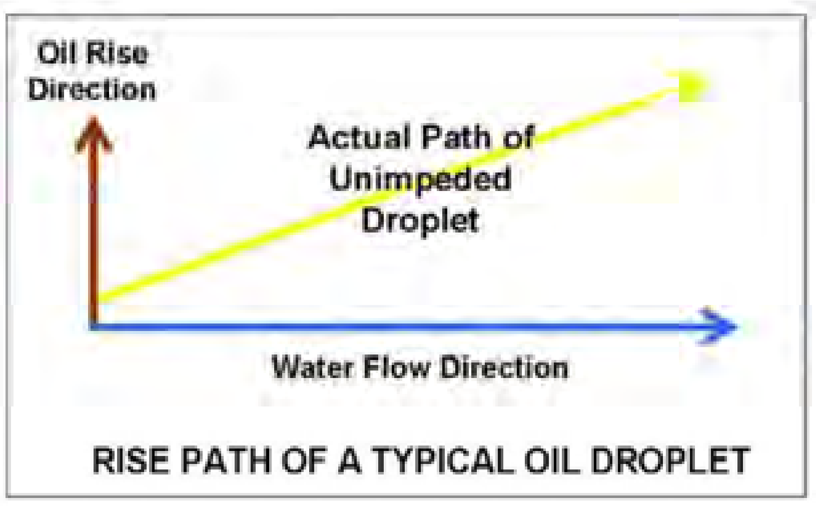

Figure 2 Rise Path of Droplets

Calculation of rise rate by this method is a gross over-simplification of actual conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Most droplets are spherical, but really large droplets when rising exhibit trailing tails much like raindrops (although inverted because the tails extend downward behind the drops). The tails are due to the droplet being distorted by the hydrodynamic drag noted above.

Droplet rise follows Stokes' 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 Stokes' law, but they still rise very quickly and are easily removed. 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' 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 (droplet) size?
2. What is viscosity of the continuous liquid?

The viscosity of the continuous liquid is readily obtained from literature data - it is dependent upon the operating temperature of the water. 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 by testing samples in the laboratory, but oil droplet size information is much more difficult to obtain. The droplets encountered in normal field operation vary widely in size from particles less than 5 microns (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.

API PUBLICATION 421 DESIGN ASSUMPTIONS AND CRITERIA

The latest edition of the API design method is Publication 421. Publication 421 provides a calculation method for determining oil-water separator sizes based on their criteria, which provides adequate removal for recycling captured oil. There are several reasons why this method should not be used for designing equipment for environmental protection use:

1. The procedure outlined in Publication 421 makes the basic assumption of laminar flow within the separator. *This assumption is not valid for large empty separators, especially for the removal of small droplets in such separators. A calculation of the Reynolds Number within the separator will indicate the presence of turbulent flow conditions.*
2. The API Method makes the implicit assumption that there will be even flow across the cross-section of the separator. *This condition is not met because in addition to the inaccuracies in the performance calculation introduced by the high Reynolds Number turbulence, convection currents and "dead spots" where there is stagnant non-flowing water within the separator. Dead spots can occur in the corners of the separator as well as in other areas.*
3. The API method also makes the assumption of an inlet droplet size of 150 micrometers, *which is inaccurate for environmental separators because a spectrum of droplet sizes will be present, most of which are smaller than 150 µ.*
4. It is therefore possible to calculate a flow rate for a given separator and that flow rate is known to be inaccurate, but the certainty of the inaccuracy is unknown. The API studies indicate that the effluent from API separators is often more than 100 mg/L.

According to API Publication 421, the design of conventional oil-water separators is based on the following constraints and recommendations:

- Horizontal velocity through the separator should be less than or equal to 3 ft/min or equal to 15 times the rise rate of the oil globules, whichever is smaller
- Assumes an oil-globule size of 0.015 cm
- Water depth of the separator should not be less than 3 ft (to minimize turbulence caused by oil/sludge flight scrapers and high flows), and commonly not greater than 8 ft
- The ratio of the separator depth to the separator width normally ranges from 0.3 to 0.5
- Separator width typically ranges from 6 ft to 20 ft and conforms to the standard dimensions for flight scraper shaft length specified for sludge removal
- A minimum of two separator channels is suggested, so that one channel is available for use when it is necessary to remove the other from service for repair or cleaning

- Separator length-to-width ratio of at least 5 is recommended to provide more uniform flow distribution and to minimize the effects of inlet and outlet turbulence on the main separator channel

A typical API separator, installed in a refinery in South America, is shown in Figure 3 below. For reference, this unit is 20 feet wide x 12.5 feet deep x 144 feet long. It is operates at 2061 US GPM and a measured effluent of 252 mg/l, which would not meet the operating criteria of the US Clean Water Act for no sheen on the outlet water.

Figure 3 – Refinery API in South America

DO THEY WORK WELL ENOUGH FOR ENVIRONMENTAL PURPOSES?

The best indication of whether or not equipment like this works satisfactorily is actual field operating data, and the best source of data on API separators is the API. API Publication 421 includes a Table C-1 entitled *Selected results of 1985 API oil water separator survey: conventional separators.*

This table includes results from testing of 32 separators in various facilities owned by API members. The age of these separators ranges from almost new to 40 years old, and the design flow rates range from 100 US GPM to 12,000 US GPM.

The tested effluents in milligrams per liter range from a minimum of 15 up to a maximum of about 2000 with most of the results being in the 100 to 400 mg/L range.

The lowest results were 10 to 15 mg/L in a system 74 feet long by 15 ½ feet wide by 5 ½ feet deep and flowing at an actual flow of 130 US GPM. The design flow rate on this system was 200 US GPM and the oil is of exceptionally low specific gravity – 0.82.

The highest specific gravity listed was 0.94 and that separator which was 23 feet long by 8 feet wide by 3 feet deep and designed for 100 US GPM but flowing at only 70 US GPM listed an effluent of 75 mg/L.

The South American refinery API does not produce an acceptable effluent. The effluent from this separator has been measured at 252 mg/l.

Although the test information included in API 421 is years old, the physics of separating the oil and water by use of Stokes' law in large empty tanks has not changed. If the criteria of Stokes' law are met, the performance of the separator can be accurately predicted. If these criteria are not met, even with the addition of some of the safety factors that the API suggests, the separator will not be expected to meet the predicted performance.

The API 421 document (section 2.3) sums this up: ***"Based on the 1985 API refinery survey of 32 conventional separators, such separators should not be expected to achieve effluent oil levels lower than 100 parts per million."***

COALESCING PLATE SEPARATORS:

Various types of coalescing plate separators have been used to 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 coalescing plate separators substitute sophisticated design for the settling time provided in pure gravity separators, so they can be much smaller for the same flow rate and conditions. The closely spaced plates make achieving laminar flow much easier than in empty-tank API 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.

Inclined plate separators

Inclined plate separators have been used with some success for many years. 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 and then migrate along the plate until they reach the surface. Plates in this type system are usually 3/4" apart. This means that the vertical rise distance that the droplets must travel over is greater than 1". Figure 4 below illustrates this type separator.

Advantages of this system include better efficiency at removing both solids and oil and resistance to plugging with solids.

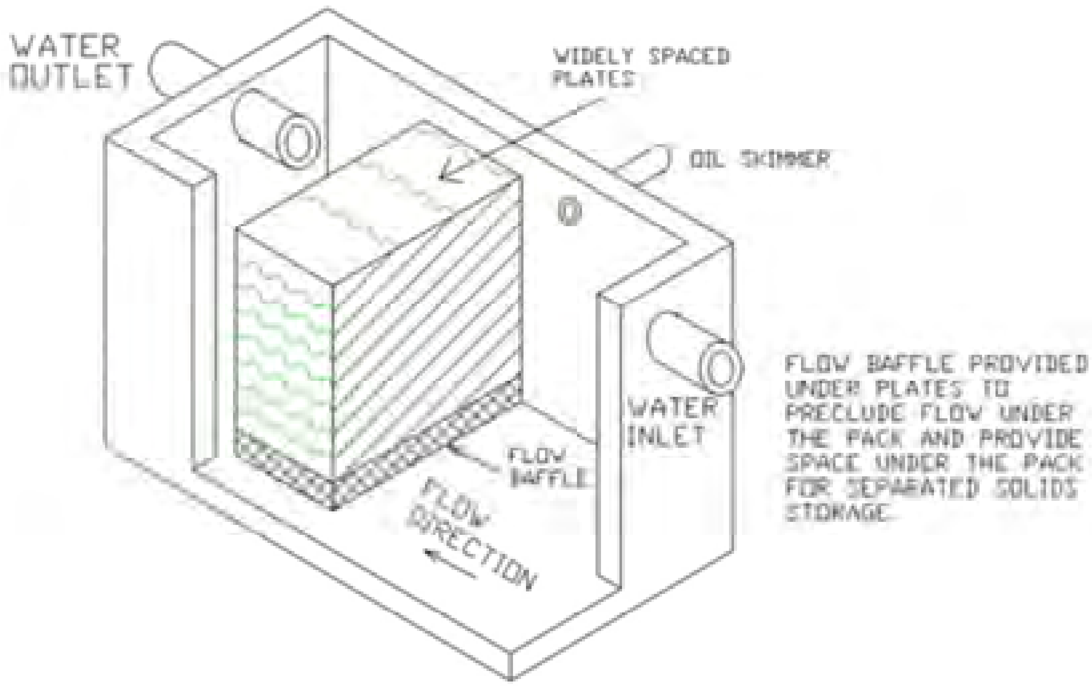

Figure 4: Inclined plate separator

Disadvantages are that large size units are required for fine droplet removal and installation costs are higher due to unit size. Because the coalescing plates normally utilized are fiberglass (which is not oleophilic “oil loving”), either more coalescing volume must be provided or a lesser degree of separation accepted.

Flat corrugated (horizontal sinusoidal) plate separators

Flat corrugated plate separators were pioneered by the General Electric Company's engineers in the 1970s. These systems are manufactured of oleophilic polypropylene plates stacked in vertical stacks and fastened into packs with rods or wires. See Figure 5 below.

Figure 5: Typical Horizontal Corrugated Plate Installation

The system works by causing the oil to collect and be separated from the water using a combination of laminar flow coalescence and oleophilic attraction. Slowing the flow of water to such low velocities that laminar flow regimes exist minimizes turbulence. Turbulence causes mixing of the oil and water and reduces oil droplet sizes. Stokes' law teaches that larger droplets will rise faster, and thus, separate better.

The oleophilic nature of the plates captures the oil droplets and encourages them to coalesce into larger ones, which will rise faster.

These plates provide better separation than could be achieved 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. The performance of the system is better than the inclined modules because the plates are closer together, and thus, the droplets have less distance to rise before encountering another plate. Plates in this type system are usually 1/4" to 1/2" apart. This means that the droplets must rise approximately 0.4" for the 1/4" spacing and 0.7" for the 1/2" spacing. Because the vertical rise distance to be covered is less than for the inclined plate systems, the same size particle is separated in a lesser time. From a different perspective, 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 solid particles because no provisions for automatic solids removal have been made in the plate design.

Many API separators have been retro-fitted with plates to increase efficiency at the same flow rate or to allow greater flow rates at the same efficiency.

Multiple angle plate separators

Multiple angle plate separators were developed to take advantage of the virtues of the horizontal sinusoidal separator plates while eliminating as many of the disadvantages as possible.

The plates are corrugated in both directions, making a sort of "egg-crate" shape. Spacers are built into the plates, constructed so that two spacings (nominal 8mm and 16mm) can conveniently be made. Figure 6 below shows a typical coalescing module including oil ports and solids dump holes.

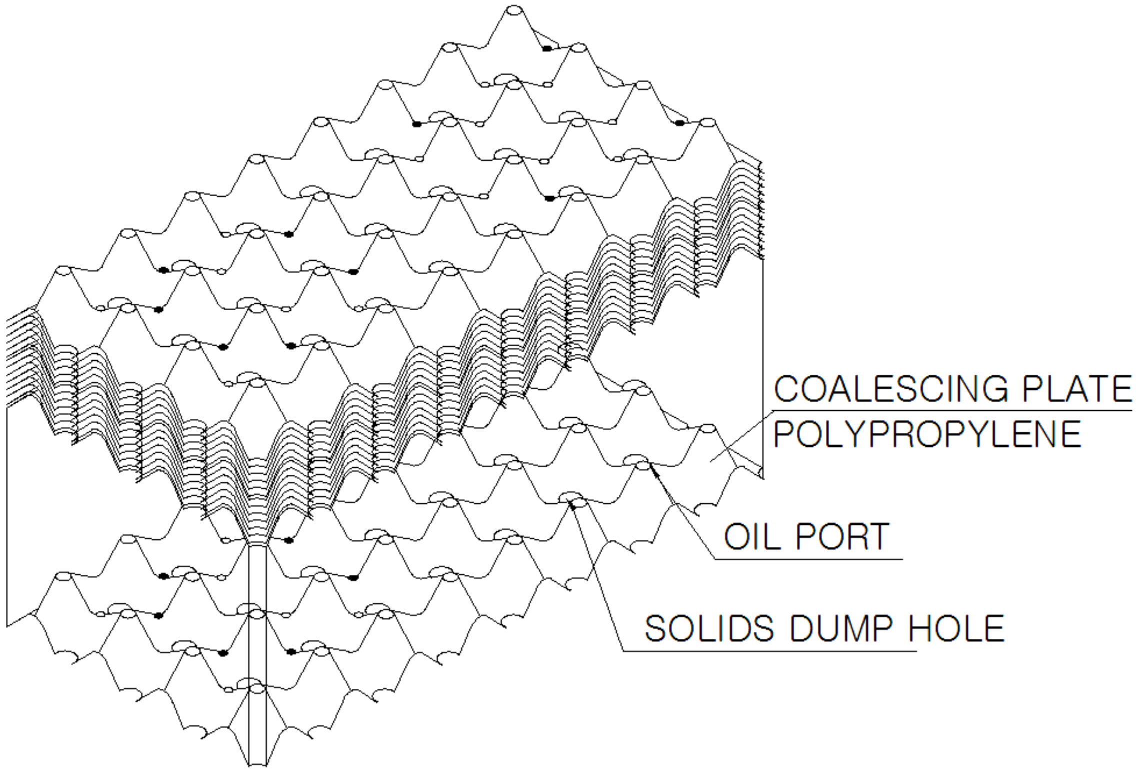

Figure 6: Typical Coalescing Module

Advantages of the multiple angle plate system are:

a) 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 a solids removal hole. The solids drop directly to the bottom of the pack through the holes.

b) The supports that form part of the package also provide a space under the plates that provides a solids collection area.

c) The double corrugations provide surfaces that slope in all directions so that all of the coalesced oil can migrate easily upward.

d) The upper support system provides a solids and oil dam that discourages bypassing solids above the plate pack into the effluent.

e) The holes in the plates that constitute the oil rise paths and solids removal paths also provide convenient orifices for insertion of cleaning wands. Inclined pack systems are not provided with such holes and are more difficult to clean when plugged with solids.

The multiple angle plates may be used in either above-ground units, or in below-grade concrete vaults, either installed directly in the concrete vault or indirectly in a metal housing. The advantages of the above-ground units are that they are factory fabricated and require a minimum of field installation time.

Figure 7: Typical Vault Utilizing Multiple Angle Plates, Partially Assembled
(Photo courtesy Langley Concrete, Langley BC)

Most large units are designed with plates installed within in-ground vaults. The primary advantages of vault installations are that the cost per US GPM of flow is low and the below-grade installation is both convenient for gravity flow applications and does not take up valuable floor space.

Retrofits of API Separators:

In 1996, Kirby Mohr was asked to redesign two existing concrete API separators installed in a refinery in the northeastern United States. The intent of the redesign was increasing the allowable flow and providing better quality effluent. This redesign included splitting each of the nominal 4000 GPM separators into two separators. The four separators were then fitted with coalescing media to give a flow rate of 5000 GPM each -- a total of 20,000 GPM. This was the big increase in capacity the customer wanted: from a total capacity of 8000 GPM to 20,000 GPM. The coalescing media that was installed was manufactured of UV protected polypropylene.

Over the next 17 years, the coalescing systems performed very well producing effluents that were usually less than 5 mg per liter. In 2013, it was decided that it was time to replace the coalescing media in those four separators and new media was chosen for the replacement. The separator replacement was very simple, using some of the previous brackets and adding some additional ones. The new media utilized is also UV protected and is expected to have a similar long effective lifespan.

Figure 8 below shows the installation of the new black UV protected media in one of the four large separator bays.

Figure 8 API Retrofit in Refinery

SIZE COMPARISON:

Figure 9 below shows a comparison of the South American refinery API separator mentioned above and a coalescing plate separator (***drawings below are to scale***). Both separators are designed for 2061 US gpm and oil specific gravity of 0.908.

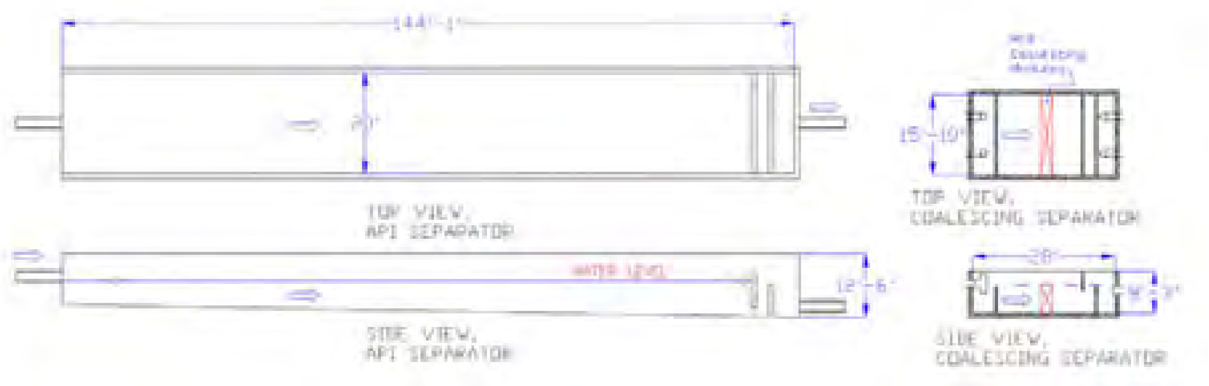

Figure 9: Comparison of API and Coalescing Separators

Please note the (actual measured) effluent from the API separator is approximately 250 mg/l and the much smaller Coalescing Plate separator is designed for less than 10 mg/l in the effluent.

CONCLUSIONS AND RECOMMENDATIONS

Environmental regulations are steadily becoming more restrictive and requiring lower concentrations of hydrocarbons in effluent water. Some localities require lower effluent standards than even the EPA mandates.

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.

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.

Coalescing plate separators offer much better performance than API (and especially API *type* separators) in smaller footprint devices and often cost less as well. Most API separators can be retrofitted with coalescing media to improve performance or increase allowable flow rate or both.

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