Low Reynolds Number Oil /Water Separator HD Q-PAC® Results Superior to Those Predicted by Stoke's Law

Abstract

Oil/water separators are commonly designed using Stoke's Law. Yet field results in oil/water separation units using HD Q-PAC® as the coalescing media have been better than Stoke's Law would have predicted. This can be explained theoretically in terms of extremely low, < 100, Reynolds Number in laminar flow through HD Q-PAC®.

Introduction

Most Class I oil/water separators in the USA as well as many around the world are designed according to guidelines given in The American Petroleum Institute Bulletin 421[1]. When treating storm water, no national efficiency standard exists in the United States. Local water authorities commonly specify required effluent water quality, most often between 10 – 50 mg/L. API 421 is often cited in regulatory publications published by various state, provincial and national governments[2,3,4] as well as many research organizations[5]. As a result, many firms that manufacture and market oil/water separation equipment design their vessels based upon this standard[6,7,8] as well as local requirements. API 421 calls for ***coalescing media*** of inclined (45º to 60º) parallel plates of ¾" (19 mm) to 1.5" (38 mm) separation and removal of droplets 60 microns diameter and larger. API 421 does not specify a water quality exiting the OWS but does suggest 50 mg/L of oil in the water being discharged. API 421 also does not mention Reynolds Number. However N_{Re} of <500 is a common industry design parameter in an oil/water separator. This is to ensure laminar flow of water (no turbulence) as the water passes through the vessel. The definition[9] of this parameter is:

$$N_{Re} = (\rho \; V \; D) \,/\, \mu$$

ρ = density of water, lb_m/ft^3 (g/m^3)
V = superficial liquid velocity, ft/hr (cm/s)
D = characteristic (hydraulic) diameter, ft (cm)
μ = viscosity of water, lb_m/hr – ft (dyne sec/cm^2)

The Reynolds Number is dimensionless. N_{Re} is used to define flow type in both English and metric system, so long as the units are consistent per the example above. Common industry practice has been to design oil/water separators using the rise rate of an oil droplet in a column of water as described by Stoke's Law:

$$V = (2gr^2)\,(d_1\text{-}d_2) \,/\, 9\mu$$

V = rise velocity of oil droplet within the water column, ft/hr (cm/sec)
g = acceleration of gravity, ft/hr^2 (cm/sec^2)
r = radius of the oil droplet, ft (cm)
d_1 = density of water, lb_m/ft^3 (g/m^3)
d_2 = density of oil, lb_m/ft^3 (g/m^3)
μ = viscosity of water, lb_m/hr – ft (dyne sec/cm^2)

Stoke's Law predicts that as the radius of the oil droplet increases, the velocity of droplet rise in the water column increases per the square of the radius. Therefore the purpose of the coalescing media in an oil/water separator is to provide suitable surfaces for oil droplets to contact where the droplets then combine, or coalesce, as the oily water flows through the separator. Oil removal from the water is greatly enhanced as oil droplet size increases. Most often in the past, coalescing media has been designed with various alterations of inclined, corrugated plates of various spacings, often 0.5" (13 mm) to 0.25" (6 mm) between plates versus the 0.75" to 1.50" specified by API 421. The smaller spacing is an effort to improve coalescing of the oil droplets – and hence improve oil removal efficiency. However, closely spaced plate media is also known to be prone to plugging and fouling.

CEN EN 858-1

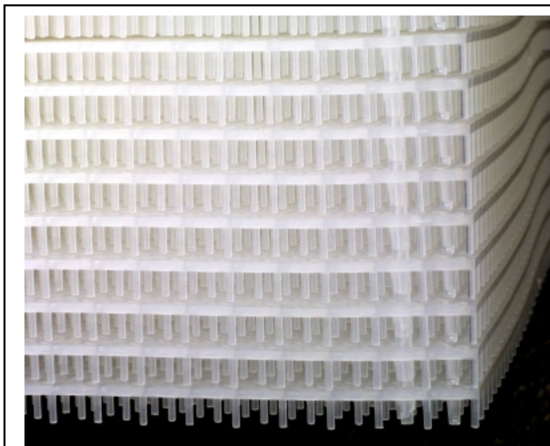
The European Union adopted a performance standard, applicable within the European Union, for Class I oil/water separators March 8, 2001[10]. This standard specifies a very low oil content in the water leaving the oil/water separator vs. what is allowed by API 421. Summarized, the performance test requirements of EN 858-1 are:

Light Liquid:	density 0.85 g/cm^3 (fuel oil)
Water:	potable or purified surface water
Solubility of Light Liquid:	nil, unsaponifiable
Water Turn Over:	minimum of four volumes of test unit
Liquid Flux:	25 – 40 m^3/hr-m^2 (10 – 15 gpm/ft^2)
Inlet Oil Concentration:	4250 mg/L
Maximum Residual Light Liquid:	5 mg/L (as measured by IR spectroscopy)

Therefore, this standard calls for oil droplet removal efficiency of 99.88%. Note that the EN 858-1 standard makes no allowance for minimum oil droplet size. This standard has proven, until recently, to be extremely difficult to meet.

HD Q-PAC® Coalescing Media

HD Q-PAC® supplied by Lantec Products has routinely not only achieved, it has exceeded the EN 858-1 test standard. This has been confirmed both by independent testing[11] as well as by numerous reports from operating field units[12]. HD Q-PAC® routinely achieves ~ 1 mg/L residual oil effluent concentration vs. 5 mg/L as called for in the EN 858-1 (99.98% removal efficiency vs. 99.88% as called for by the European Union standard).



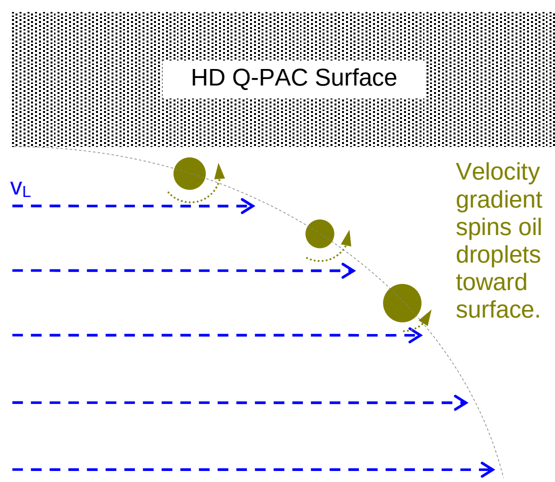
HD Q-PAC®
USA Patent #5,458,817

HD Q-PAC® Low Reynolds Number Oil /Water Separator

HD Q-PAC® achieves a much lower Reynolds Number than has traditionally been possible in oil/water separators. Using the equivalent hydraulic (characteristic) diameter of HD Q-PAC® to calculate N_{Re}, at typical separator liquid fluxes, the values of N_{Re} obtained are:

HD Q-PAC® Liquid Flux		Reynolds Number
gpm/ft^2	$m^3/hr\text{-}m^2$	N_{Re}
10	25	30
13	32	40
20	49	60

The fluid dynamics of oil/water separation at very low Reynolds Numbers have been the subject of a detailed study.[13] When oily water flows slowly over a fixed surface, the liquid velocity near the surface is slower due to friction. If water flows slower on one side of an oil droplet than on the other side, the droplet will rotate. Rotating oil droplets are deflected towards the surface where velocities approach zero. This allows them to coalesce faster than Stoke's Law would predict for droplets in stagnant water. Laboratory tests have shown that this "curve ball" effect of droplet rotation becomes pronounced at Reynolds Number below 100.



Liquid velocity profile at low Reynolds Number

The self-cleaning design of HD Q-PAC®, all rounded surfaces with many perpendicular rods, allows for its polypropylene elements to be spaced less than 5 mm apart without becoming plugged by any suspended solids present in the oily water. This spacing is much smaller than typical spacing between elements of traditional coalescing media as previously discussed. As result, an extremely low Reynolds Number of 60 is achieved even at a liquid flux of 20 gpm/ft^2 (49 $m^3/hr\text{-}m^2$), as noted in the table above, when using HD Q-PAC® as the coalescing media in an oil/water separator.

Conclusion

The remarkable ability of HD Q-PAC® to accelerate oil/water separation and attain efficiency superior than called for by EN 858-1 is explained here based upon established scientific principles. These results confirm that at extremely low Reynolds Numbers less than 100 Stoke's Law does not account for the observed coalescing rate of oil droplets in an oil/water separator using HD Q-PAC®. Stoke's Law can thus be used as a guide, but should not govern, the design of an oil/water separator when HD Q-PAC® is used as the coalescing media.

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