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Design of Industrial Gravity Type Separators for the Hydrocarbons and Heavy Oil-Water Separations

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Abstract

Hydrocarbon and Heavy Oil-Water Separators are fall in major mass transfer operations and a key component of chemical process industries. They have wide applications in purification and especially in water treatment processes. Many technical papers have been written on the Hydrocarbon and Heavy Oil-Water separator design and vast amounts of information are also available in corporate process engineering design guidelines. The purpose of this work is to provide a comprehensive current design status of Hydrocarbon and Heavy Oil-Water Separators. This type of Hydrocarbon and Heavy Oil-Water Separators which is presented in this work is usually design and used for the separation of hydrocarbons produced during Fischer-Tropsch Synthesis of green diesel from synthesis gas.

Keywords: Oil-water separators, water treatment, gravity decanter, fischer-tropsch synthesis.

Introduction

Oil-Water Separators are used to remove the oil, grease, hydrocarbons and sediments from the waste water in chemical process industries. They are specially installed at industrial and maintenance areas such as aircraft and vehicle maintenance and washing and other activities involving petroleum oils and lubricants t separate oils at low concentrations from water. They are come into two categories. One is called as conventional separators that are designed on the basis of guidelines provided by the American Petroleum Institute (API) and 2nd type of parallel plate separators[1,2].

Gravity separators use process that relies on the different densities of oil, water and solids for successful operation. The waste water is fed into a vessel sized to provide a quiescent zone off sufficient retention time to allow the oil float at to the top and the solid settled to the bottom.

Gravity oil water separators or decanters are used to separate the relatively low solubility petroleum products in water and the difference between the specific gravity of water and the specific gravities of the petroleum products[3].

Environmental regulation of oil in salt water disposal from oil and gas operations are becoming more stringent and the high value of crude oil make 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. Many separation devices currently used in the oil production industry are similar or identical to those used a hundred year's ago[4].

Oil separators can be fitted to surface water drainage systems to protect the environment from pollution by oils. They separate the oil from the water, and then retain the oil safely until it is removed. They are installed to contain oil leaks from vehicles and plant and accidental spillages. To be effective, oil separators need to be correctly designed, installed and maintained[5].

Separator sizing must satisfy several criteria for good operation during the lifetime of the producing field.

Provide sufficient time to allow the immiscible gas, oil and water phases to separate by gravity. Provide sufficient time to allow for the coalescence and breaking of emulsion droplets at the oil-water surface. Provide sufficient volume in gas space to accommodate rises in liquid level that results from a surge in liquid flow rate. Provide removal of the solid that settle at the bottom of separator. Allow for variation in the flow rates of gas, oil and water in to the separator without adversely affecting separation efficiency[6].

This oil water separator is designed to separate the hydrocarbons and water produced during the Fischer-Tropsch Synthesis. The reaction involved and the production of water along with green diesel is.

The major overall reactions involved in the Fischer-Tropsch Synthesis are as follows.
Paraffin $(2n+1)\ H_2 + nCO \rightarrow / \ CnH_2n{+}02 + nH_2O$
Olefins $2nH_2 + nCO \rightarrow / \ CnH_2n + nH_2O$
Water Gas Shift Reaction $CO + H_2O \rightarrow /1 \ CO_2 + H_2$

Side reaction involves in this process are:
Alcohols $2nH_2 + nCO \rightarrow CnH_2n0{+}2O + (2n-1)4H_2O$
Boudouard Reaction $2CO \rightarrow C + CO_2$

Catalyst Modification will takes place in following reactions:

Catalyst Oxidation/Reduction $MxOy + yH_2 \leftrightarrow /1\ yH_2O + xM$

$MxOy + yCO \leftrightarrow /1\ yCO_2 + xM$

Bulk Carbide Formation $yC + xM \leftrightarrow MxCy$

Methodology

Design Calculations: The first step in developing a sizing procedure is to determine which phase is dispersed. The value of the parameter θ, defined by equation-1 in table-1, and could be used as a guide to determine the dispersed phase. After calculating θ, then use Table 1 to identify the dispersed Phase.[7]

$$\theta = \frac{V'_L}{V'_H}\left(\frac{\rho'_L \mu'_H}{\rho'_H \mu'_L}\right)^{0.30} \qquad (1)$$

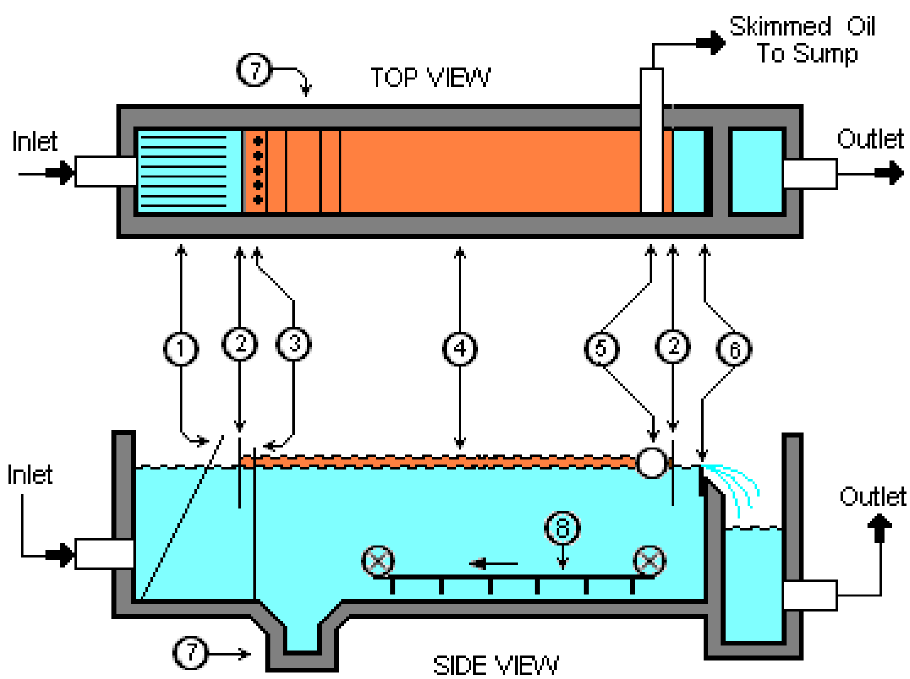
Where[8]: θ = Dispersed Phase Parameter in Liquid-Liquid Separation. V'_L= Volumetric Flow rate of light liquid Phase = Mass Flow Rate of hydrocarbon phase / Density of hydrocarbon = 428318.455 kg/hr. / 3600 sec x 512.018 kg/m^3 = 0.232 m^3/sec V'_H =Volumetric Flow Rate of Heavy Liquid Phase. = Mass Flow Rate of Water / Density of water = 1526.022 Kg/hr. / 3600 x 748.592 kg/m^3 = 5.662x10^{-4} m^3/sec ρ'_L= Density of Light Liquid Phase. = 512.018 kg/m^3 ρ'_H=Density of Heavy Liquid Phase. = 748.592 kg/m^3 μ'_H=Viscosity of Heavy Liquid Phase. = 0.096 cp. μ'_L =Viscosity of Light Liquid Phase. = 0.167 cp.

Put all these values in (1) we get θ = 3.09

So from this table-1 we get that heavy phase (water) is dispersed phase while light phase (hydrocarbons) are continuous phase.

Property Estimation[8]:

Density of water at 543K = 748.592 Kg/m^3,
Density of Hydrocarbons at 543K = 512.018 Kg/m^3,
Mass Flow rate of dispersed phase (water) = 84.779 Kgmole/hr.,
Molar Flow rate molecular weight = 84.779×18 = 1526.022 Kg/hr.,
Mass Flow rate of continuous phase (Hydrocarbon) = 2953.921 Kmole/hr.,
Molar Flow Rate molecular weight =2953.921×145 Kg/Kmole = 428318.455 kg/hr.,
Viscosity of Hydrocarbon = 0.167 centipoise.



1. **Trash trap (inclined rods)**
2. **Oil retention baffles**
3. **Flow distributors (vertical rods)**
4. **Oil layer**
5. **Slotted pipe skimmer**
6. **Adjustable overflow weir**
7. **Sludge sump**
8. **Chain and flight scraper**

Figure-1
Oil-Water Separator

Table-1
Property Estimation

Dispersed Phase Parameter	**Result**
<0.3	Light Phase always Dispersed
0.3-0.5	Light Phase probably Dispersed
0.5-2.0	Phase inversion probable, design for worst case
2.0-3.3	Heavy Phase probably Dispersed
>3.3	Heavy Phase always Dispersed

Velocity Dispersed Phase : Let d_d = Diameter of dispersed phase = 300 μm, As we know that[6]

$$u_d = \frac{d^2 g(\rho_d - \rho_c)}{18\mu_c} \quad (2)$$

Here: d_d = Diameter of dispersed phase (assumed value in μm), g = Gravitational Acceleration 9.81 m/sec^2 ρ_d= Density of dispersed phase. (748.592 kg/m^3) ρ_c= Density of Continuous phase. 512.018 kg/m^3 μ_C= Viscosity of Continuous phase. 0.167 cp

Putting all the above values in (2) we get

$$u_d = \frac{d^2 g(\rho_d - \rho_c)}{18\mu_c} = \frac{(300 \times 10^{-6})^2 \times 9.81 \times (748.592 - 512.018)}{18 \times 0.167} = 0.0695\,\frac{m}{sec.}$$

Continuous Phase Volumetric Flow Rate: The volumetric flow rate in the continuous phase can be calculated as[9].

$$L_c = \frac{\text{Flow Rate of Hydrocarbons}}{\rho_c \times 3600} = \frac{428318.545}{512.018 \times 3600} = 0.232\,\frac{m^3}{sec.}$$

Time of Separation: Time of separation can be determined as follows;[7]

$$t = \frac{100\mu_c}{\rho_d - \rho_c} \quad (3)$$

Here: μ_C= Viscosity of Continuous phase. 0.167 cp ρ_d= Density of dispersed phase. 748.592 kg/m^3 ρ_c= Density of Continuous phase. 512.018 kg/m^3, So by putting above respective values in (3) we get

$$t = \frac{100\mu_c}{\rho_d - \rho_c} = \frac{100 \times 0.167}{748.592 - 512.018} = 4.23\text{min}$$

Diameter and Height of Tank: To calculate tank area we have the relation; Volumetric flow rate of continuous phase/Velocity of continuous phase = Area of liquid interface

$$\frac{L_c}{U_c} = A_i \quad (4)$$

Here: L_C = Volumetric Flow Rate of Continuous Phase 0.232 m^3/sec, U_C = Velocity of Continuous phase 0.0695 m/sec. So by putting values in (4) we get

$$A_i = \frac{0.232}{0.0695} = 3.36m^2$$

Vessel radius "r" is as so putting value of interfacial area we get.

$$r = \sqrt{\frac{A_i}{\pi}} = \sqrt{\frac{3.36}{3.36}} = 1$$

As diameter is twice as radius so,

$D = 2m = 2 \times 1 = 2m$

Height is usually taken sufficient as 2 times as that of the respective diameter so vessel length is

$L = 4m$

L/D Ratio: For a satisfactory design the L/D ratio should be between 2 and 5 here L/D = 2 which is satisfactory .

Liquid Hold Up Volume: To calculate hold up volume we have the relation as follows[10]

$$\text{Liquid Hold Up Volume} = tL_c \quad (5)$$

Here: t = Separation time 4.23min L_C = Continuous Phase volumetric flow rate 0.232m^3/sec, Liquid Hold Up Volume = $tL_c = 4 \times 0.232 \times 60 = 55.68m^3$

Vessel should be 95% full so that its volume is as follows,

$$\text{Volume of Vessel} = \frac{55.68}{0.95} = 58.61m^3$$

Height of Fluid, Hydrocarbon and Water in Vessel: Fraction of tank volume occupied by liquid will be 95% and for a vertical cylinder this means liquid depth is 90% of tank.
So,

$Z_1 = 0.90 \times L$, $Z_1 = 0.90 \times 4$, $Z_1 = 3.36m$

Liquid interface is 50% between vessel floor and liquid surface,
Then: $Z_3 = 0.5 \times 4$ $Z_3 = 2m$
And Z_2 is calculated as follows from (6)

$$Z_2 = \frac{(Z_1 - Z_3)\rho_c}{\rho_d + Z_3} \quad (6)$$

Here: Z_1= height from datum to light liquid overflow (m), Z_2= height from datum to heavy liquid overflow (m), Z_3= height from datum to the interface (m)

$$Z_2 = \frac{(Z_1 - Z_3)\rho_c}{\rho_d + Z_3} = \frac{(3.6 - 2)512.018}{748.592 + 2} = 3.09\text{m}$$

Checking:

$$d_d = \sqrt{\frac{18u_d\mu_c}{g(\rho_d - \rho_c)}} \quad (7)$$

Here: d_d = Diameter of dispersed phase (assumed value in μm) g = Gravitational Acceleration 9.81 m/sec^{2,} ρ_d= Density of dispersed phase. 748.592 kg/m^3ρ_c= Density of Continuous phase. 512.018 kg/m^3)μ_C= Viscosity of Continuous phase. 0.167 cp, U_d= Velocity of Dispersed Phase 0.0695 m/sec

$$d_d = \sqrt{\frac{18u_d\mu_c}{g(\rho_d - \rho_c)}} = \sqrt{\frac{18 \times 0.0695 \times 0.167 \times 10^{-3}}{9.81(748.592 - 512.018)}} = 298\mu\text{m}$$

d_d= 298 μm which is less that the supposed 300 μm thus design is applicable and satisfactory.

Results and Discussion

In this work we present a basic design methodology for the heavy oil, hydrocarbon-water separators as follows.

Table-2
Methodology

Oil-Water Separator	
Flow Rates	Feed = 3038.31 K mol/hr. Lighter Fractions = 1772 K mol/hr. Heavier Fractions = 1181.56 K mol/hr.
Dispersed Phase	Water
Continuous Phase	Hydrocarbons
Specifications	
Volume of Vessel	58.61m^3
Diameter	2m
Height	4m
Total Depth of Liquid	3.6m
Height of Hydrocarbons Flow	1.2m
Height of Water Flow	3.09m
Surge Time	4.23 min

Conclusion

In this research we design a Hydrocarbon and Heavy-Oil Water Separator for the separation of hydrocarbons produced during the conversion of synthesis gas in to the green diesel in Fischer-Tropsch Synthesis. Our Gravity Type Separator design is satisfactory because of its optimized dimensions of Volume 58.61m^3, Diameter 2m and Height 4m.

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