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ASSESSMENT OF SKIMMERS IN PRODUCED WATER TREATMENT ON A FLOATING PRODUCTION STORAGE AND OFFLOADING (FPSO) FACILITY

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ABSTRACT

Pollution arising from produced water from the separation of oil and gas is one of the many environmental challenges experienced in the oil and gas industry. The inability of some separating vessel to adequately reduce the harmful materials in the produced water before discharging it has contributed to resent environmental hazards. The use of skimmers as a primary treatment vessel in the separation of oil droplets from produced water before discharge was assessed in this work. The skimmers which employ coalescence and gravity separation techniques are effective in water treatment when the outlet oil concentration is known. Optimization studies were carried out using skim plate (SP) packs placed inside skim tanks and comparing the performance to using just Skimmers. Water production rates were also varied to check the effect of a change in flow rate on the separation of the oil droplets and water. Results obtained showed that the overall efficiency was 95% separations of oil droplets when used with SP packs, with the SP packs separating two times the oil droplet size just using skim tank would. The effective length for separation to occur in a 24 in diameter separator was reduced from 16.93 ft (skimmer) to 4.23 ft (SP packs) which is a vital design parameter in offshore locations, and it also indicated that the vertical skimmers are also effective in handling solid particles.

1. INTRODUCTION

Produced water contains oil droplets and solid particles that need to be separated from it to meet certain regulations and requirements before it can be discharged into the environment (Bradley and Collins 1987). Produced water can best be described as water from underground formations that is produced at the surface during oil or gas production because it is in contact with hydrocarbon-bearing formations. The chemical characteristics of the produced water is influenced by the environment (formations and the hydrocarbons) in which it once resides. It may include water from the reservoir, water previously injected into the formation, and any chemicals added during the production processes (Clark and Veil, 2009). Irrespective of the major constituents of the produced water, it is the largest volume by-product or waste stream associated with oil and gas exploration and production. Consequently, adequate technical design approach must be installed to handle these large volumes received at the surface daily. Treatment vessels are designed to separate these oil droplets and particles from the water produced and they operate on different techniques. The concentration of the produced water is critical in the design of the treatment vessel as the water can still contain oil droplets concentration as high as 300 mg/l. Treatment has to be effective and efficient to give the desired effluent quality.

The configuration of the treatment vessel may be horizontal or vertical depending on the proposed design target and on how to increase the efficiency of separation in offshore facilities such as the floating production storage and offloading (FPSO) vessel where space is an important factor. When designing water treatment vessels, analysis is carried out to ascertain the most cost-effective treatment vessel which will take up less space and has greater efficiency. Skimmers are the simplest form of settling tanks and are normally designed to provide long residence times during which coalescence and gravity separation occurs (Arnold and Stewart, 2008). The function of this kind of equipment is to cause the oil droplets, which are dispersed in the water continuous phase, to separate and float to the surface to be removed (Damian et al., 2012). The three basic phenomena that are used in the design of common produced water treating vessel are gravity separation, coalescence, and flotation (Arnold and Stewart, 2008). However, Man et al., 2005; Lee et al., 2007 applied gases to the stream for better flotation and improved settling which requires some energy to be supplied and air pump maintenance. The SP pack is placed inside the gravity settling section of the skimmer device and by growing a larger drop size distribution; the gravity settler is more efficient at removing oil (Zhang et al., 2007; Jeelani and Hartland, 1998). SP pack creates turbulent flow by forcing the water to flow through a serpentine pipe path which differs from other gravity settling devices. The path is sized to create turbulence of sufficient magnitude to cause coalescence but not so great as to shear the droplets below a specified size. The pipe path is similar in size to the inlet piping and thus is not susceptible to plugging.

This work is aimed at assessing the impact of skimmers and SP packs in primary separation process in FPSO, because offshore platforms are seriously faced with none availability of space. Also to assess the impact of skimmers and SP packs if variations in rates occur. The combination of this stage (skimmer and SP packs) with the primary separation stage will help in the optimization of working space in FPSO and in the reduction of the percentage of oil droplets in the produced water before discharging into the environment.

2. METHODOLOGY

The well production data obtained from surface conditions were analytically evaluated with retention time set at 10 minutes. The effective length of separation was obtained from the standard skimmer vessel diameter of 24 in, 30 in, 36 in, 42 in, 48 in, 54 in and 60 in which were selected arbitrarily, these vessel diameters are known diameter sizes that can be that can be used. Each of these skimmer vessel diameters have an effective length for separation to occur, which were used to determine the seam-to-seam length and the actual length with or without SP packs. Calculations made also varied the water production rate between 2146.5 BWPD and 750 BWPD to determine the effect of the changes in flow rate on the removal of oil droplets.

3. MODEL FORMULATION

The models formulated for determining skimmer dimensions such as effective length of separation of oil droplets from produced water, vessel diameter and seam to seam length were based on Stoke's Law and Hinze's Law (Arnold and Stewart, 2008). The equation used in this work relates the effective length of separation of oil droplets to the size (diameter) of the droplet and the diameter of the skimmer vessel used for the separation. For a horizontal cylindrical vessel assuming a condition of one half full of well streams, the effective length in which separation occurs can be determined from Equation 1 from Stokes's law (Arnold and Stewart, 2008).

$$L_{eff} = \frac{1000\, Q_w \mu_w}{d \times (\Delta S.G.)(d_m)^2} \tag{1}$$

Where d is the vessel internal diameter in inches, Q_w is the water flow rate in barrel of water per day (BWPD), μ_w is the water viscosity in centipoises (cp), d_m is the oil droplet diameter in microns and ΔSG is the difference in specific gravity between the oil and water relative to water. Equation 1 was used to determine the effective length of separation, when substituted into Equation 2 can help to determine the skimmer diameter if the retention time is known as expressed in Equation 2.

$$L_{eff} = \frac{1.4 (t_r)_w Q_w}{d^2} \tag{2}$$

Where $(t_r)_w$ is the retention time in minutes, the possibility of having a skimmer tank with a specific geometry is high with recent designs. Consequently, the width and length of a horizontal rectangular cross section skimmer tank can also be determined from Stokes's law. The condition obtained from Equation 3 for horizontal rectangular tanks can be related with the retention time to determine the optimum size for an effective skimmer tank.

$$L_{eff} = 70 \frac{Q_w \mu_w}{W \times (\Delta S.G.) d_m^2} \tag{3}$$

Where W is the width of the horizontal tank of rectangular cross section in feet (ft). The diameter of a vertical cylindrical tank can be evaluated with equation 4 by setting oil rising velocity equal to the average water velocity.

$$d^2 = 6{,}691\ F \frac{Q_w \mu_w}{(\Delta SG) d_m^2} \quad (4)$$

The F in the model is a factor that described the turbulence and short-circuiting. For small diameter (d ≤ 48 in.) skimmers F = 1.0. While for large diameter (d > 48 in.) skimmers, F = d/48 and when substituted into Equation 4, it can be written as presented in Equation 5 (Arnold and Stewart 2008). Equation 5 is when the F factor is (F=d/48) substituted into Equation 4.

$$d = 140\ \frac{Q_w \mu_w}{(\Delta SG) d_m^2} \quad (5)$$

The height of the water column in the vertical skim tanks can be predicted for some specific diameters relative to retention time as shown in Equation 6.

$$H = 0.7 \frac{(t_r)_w Q_w}{d^2} \quad (6)$$

Where H is the height of the water in ft. while the overall efficiency (E_t) in each stage of the separation can be obtained Equation 7, this is made possible due to the inlet concentration (C_i) of the water to be treated and the outlet concentration (C_o)

$$E_t = \frac{C_i - C_o}{C_i} \quad (7)$$

Table 1: Well production data obtained at the surface facility

Input Parameters	Values
Effluent quality (C_o)	50 mg/L
Concentration of soluble oil at discharge conditions	9.5 mg/L
Produced water flow rate (Q_W)	14310 BWPD
Specific gravity of produced water $(S.G.)_w$	1.05
Waste water viscosity at flowing temperatures (μ)	0.262 cp
Concentration of oil in water to be treated (C_i)	1000 mg/L
Specific gravity of oil at flowing temperature $(S.G.)_0$	0.825

4. RESULTS AND DISCUSSION

For a diameter of 24 ft, when water production rate was 2146.5 BWPD, the water column height was evaluated to be 26.0859 ft. and when the water production rate dropped to 750 BWPD, the column height also dropped to 9.114583 ft. Other results are presented in Tables 2 and 3.

Table 2: Effective length of separation for a vertical cylindrical skimmer

d (in.)	$(t_r)_w$ (min)	Q_w(BWPD)	H (L_{eff})	L_{ss} (ft)	Q_w(BWPD)	H(L_{eff}) (ft)	L_{ss} (ft)
24	10	2146.5	26.09	29.09	750	9.11	12.11
30	10	2146.5	16.70	19.70	750	5.83	8.83
36	10	2146.5	11.59	14.59	750	4.05	7.05
42	10	2146.5	8.52	11.52	750	2.98	5.98
48	10	2146.5	6.52	9.52	750	2.28	5.28
54	10	2146.5	5.15	8.15	750	1.80	4.80
60	10	2146.5	4.17	7.17	750	1.46	4.46

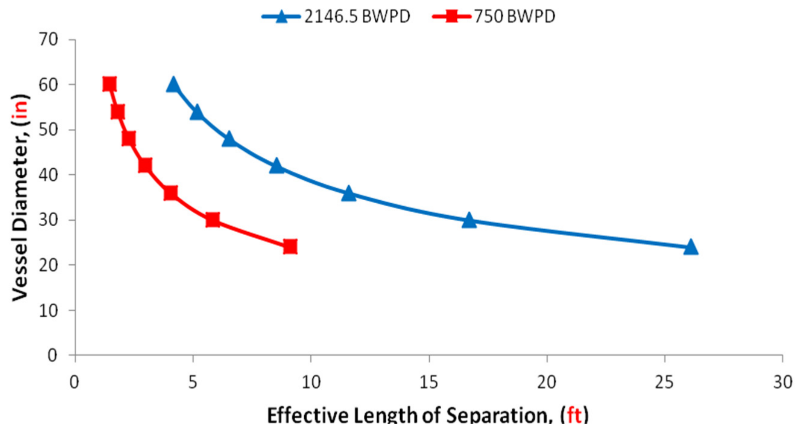

Figure 1: The Diameter and Effective length of Separation Relationship

Table 3: Effective length and actual length of separation with SP packs & without SP packs

d (in.)	Without SP packs		With SP packs	
	L_{eff} (ft.)	Actual length (ft.)	L_{eff} (ft.)	Actual length (ft.)
24	16.93	22.69	4.23	5.67
30	13.55	18.15	3.39	4.54
36	11.29	15.13	2.82	3.78
42	9.67	12.96	2.42	3.24
48	8.46	11.34	2.12	2.84
54	7.52	10.08	1.88	2.52
60	6.77	9.08	1.69	2.27

The relationship between vessel diameter and the length of interest in separation is presented in Figure 1, for a minimum retention time of 10 minutes when the flow rates are 2146.5 and 750 BWPD. In Table 2, a lower flow rate of 750 BWPD reduced the effective length of separation compared to a higher flow rate of 2146.5 BWPD and thus will ultimately save space and cost when used in an offshore facility like the FPSO. This trend is due to the reduction in the flow rate of the inlet mixture, which resulted in the reduction of the area where separation occur and also in the reduction of the seam-to-seam length. Lee and Frankiewicz, (2005) emphasized that the inlet section is crucial to proving a more uniform flow on entry into the tanks for separation. The reduction in flow rate may have resulted in a more uniform flow rate at the inlet of the tank vessel compared to when a higher flow rate was applied. The essence of this study was to reduce the percentage of oil trapped in the continuous water phase after the well stream had undergone stage separation. The introduction of SP packs creates another opportunity to strip out some oil droplets from the flowing oil-water stream into a skim tank by creating a turbulence flow regime close to the inlet location. From Table 3, it can be seen that the use of SP packs in the internal design of skimmers reduced the length of separation to half the original length and simultaneously reduced the space used. For a 24 ft diameter separator, a skimmer would effectively separate the oil droplets within the effective length of separation of 16.93 ft while the use of an SP pack gave 4.23 ft. Also in Table 3, the actual length of separation was greatly reduced with the introduction of SP packs. Consequently, the space for other internal device will reduce because the major location of interest for separation to occur has been reduced by SP packs. Hence, it follows that the use of SP pack enhances skimmer efficiency and determines the sizing of the separator and depending on preference or policy of company; such sizing can be obtained from similar data. Also, the diameter of the skimmer has an inverse relationship with the effective and actual length of separation, and this was noticed at varying flow rates.

The retention time criteria would give a plot similar to that obtained when using the vertical skim tank. This is because from the models applied (Equations 2 and 6), the effective height (or length) of separation is directly proportional to the retention time and flow rate, but inversely proportional to the vessel diameter. From the input data in Table 1 (Concentration of soluble oil at discharge conditions), theoretic evaluations were made and specification of the design of the skimmer was done to give an effluent quality which is as low as 9.5 mg/L oil concentration (Wilkinson et al., 1999). By using SP packs in the internal design of the skimmer, removal of oil droplet was more efficient. Skim tank dimensions given the water production rate of 14310 BWPD (barrels of water per day) with a retention time of 10 minutes can be gotten from any combination of diameter and effective length of separation shown in the Tables 2 and 3.

5. CONCLUSION

Based on the findings the following conclusions were arrived at in this study.

i. Skimmer vessels effectively separate oil droplets from water at small lengths due to reduction in flow rate
ii. The application of SP packs with a skimmer separates twice the size of oil droplets from the produced water at smaller distances (length) than when the skim tank is used without SP packs. This distance is reduced to a quarter of originally expected by just the skim vessels only.

6. ACKNOWLEDGEMENT

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7. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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