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CFD Analysis of Airflow in the Oil Reservoir

[1]Ch.venkatesh, [2]Mr.D.Suresh, [3]Mr. P.Sudheer rao

[1]Pg Scholar,Department of thermal engineering, Sphoorthy engineering college, Nadergul, saroornagar, Telangana.

2. Assistant Professor, Department of thermal engineering, Sphoorthy engineering college, Nadergul, saroornagar, Telangana.

3. Associate Professor, , Department of thermal engineering, Sphoorthy engineering college, Nadergul, saroornagar, Telangana.

ABSTRACT:

Computational Fluid Dynamics (CFD) and experimental tests were used to carry out a comparative study of gravity separation using skimmer tank technologies for removing low oil concentrations remaining in produced water. In this work, three technologies were evaluated; one without internals (called descendent flow technology), second one is with internals (called baffle technology) and the other is with perforate baffles. To determine the flow distribution pattern and residence time. Compare baffle technology model's result with graphical visualization from the literature. CFD results were in good agreement with experimental ones(literatures). However, the suitability of the numerical tools to study residence time was assessed. Velocity magnitude, pressure contours & vectors shows flow characteristics that help to understand and verify the main vortex structures found by CFD leading to the conclusion that the implemented CFD strategies is suitable for evaluation and design of skimmer tanks with long residence time.

INTRODUCTION

Produced water quality has become an increasingly large area of concern for the oil production industry. Production facilities have been re-evaluating their conventional approaches to oil removal from water due to increasing water cuts caused by the maturation of their oil wells, as well as a need for cleaner water for re-injection or disposal purposes. As such, the main concerns for producers are that not only do many facilities require an upgrade to their existing equipment to handle higher capacities, but also that their facilities require a more rigorous, reliable system to maintain their water quality for re-injection or disposal specifications. Conventional approaches for water de-oiling include the use of equipment such as gravity skimmer tanks, CPI's, induced gas flotation units, hydrocyclones and filters. Skimmers have been used for a long time, because on their simplicity, low cost and low maintenance.

As oil fields mature, the production of water can significantly increase. The industry perceives this excess produced water as a necessary evil that is often a liability and major cost centre. Offshore platforms are faced with additional challenges. The regulations for oil concentration in produced water discharged overboard commonly vary from 29 to 40 ppm. As the water cut increases, the retention time of existing primary separation equipment is reduced to cope with the excess produced water. Failure to handle the water quickly results in the water treatment becoming the bottleneck of the facility. Reduced retention time in the separation equipment can result in difficulties de-oiling the produced water to within discharge regulations.

1.1 OIL/WATER SEPARATION THEORY

The separation of oil from water and the design of oil/water separation equipment are governed by Stokes' Law which states:

$$V_r = g\, d^2 (\rho_w - \rho_o) / 18\, \mu$$

V_r = rise velocity of oil droplet

g = acceleration due to gravity

d = oil particle diameter

ρ_w = density of water

ρ_o = density of oil

μ = viscosity of water

From Stokes' Law, several parameters can be manipulated to augment the separation of oil from water. However, the single most effective parameter that helps facilitate the separation process is the diameter of the oil droplet. The manipulation of the oil droplet diameter will have the largest impact on the rise velocity. Other issues play an important role in the separation efficiency process. In order to correctly address the de-oiling issues that exist, it is vital to better understand the characteristics of the produced water and the dispersed oil. Hydrocarbon concentrations should be noted and tracked All equipment that exists for separating oil from water uses Stoke's Law as the basic fundamental operating principle. Each class of oil water separators have their own specific limitation which is the size of the droplet that can be effectively separated from water. The removal of oil from water can be accomplished by the use of several wellknown and widely accepted techniques. However, the performance of any given separation technique will depend entirely on the condition of the oil-water mixture. Present techniques for the separation of oil from water are based on their difference of density. Stoke's Law states that rising velocity Vr is a function of the square of the oil droplet's diameter. From Stoke's Law, it can be seen that droplet size has the largest impact on rising velocity to a collection surface and thus the easier it is to treat the water. Consequently, the bigger the droplet size, the less time it takes for the droplet to rise to a collection surface and therefore the easier it is to treat the water.

The oil in water can be present as free-oil, and/or emulsified, and/or dissolved states in different proportions. This oil droplet size distribution is one of the most important factors affecting the design of oil-water separators. Free-oil is defined as an oil droplet of 150 microns or larger which will float immediately to the surface due to its large size and high rise velocity. Emulsion is oil which is dispersed in the water in a stable fashion due to its small diameter and thus to its low rise velocity. Emulsions can be found in two types : mechanical emulsions and chemical emulsions. Mechanical emulsions are created through the process of pumping, large pressure drops through chokes, control valves, and otherwise mixing the oil-water solution. Chemical emulsions are generally intentionally formed using chemicals to stabilize the emulsions for an industrial process need or other use. Gravity separation is a popular mechanism commonly used for the removal of oil from water. This process primarily affects free oil. Tight oil emulsions and dissolved oils will not be removed by gravity separation alone. The objective in treatment of water containing emulsified oils is to destabilize the emulsion so that the oil will separate by gravity or flotation. Essentially what is done is to promote interdroplet contact with the purpose of developing larger droplets that will be easier to remove. Once the emulsion is broken, the same removal techniques applicable to free oil can be utilized. Small oil droplets are always difficult to separate. The smaller the droplets, the lower their rising velocity will be. A prerequisite for efficient separation is, therefore, that oil droplets coalesce (become larger and rise more rapidly). These small droplets and the concentrations of these droplets that exist in the water need to be properly measured in order to select the correct oil/water separator. A Size Distribution Curve is imperative to measure. This information is difficult to obtain if one wishes to measure realistic values indicative of the process.

Thus the size distribution curve must be measured in real-time and on-line.

LITERATURE SURVEY

For many years hydrocyclones have been used in different industries such as pulp and paper production, food processing, chemical industries, power generation, metalworking, and oil and mining industries. Both solid-liquid and liquid-liquid separation are possible with this technology. Most of the available literature on hydrocyclones is related to solid-liquid separation. Since the 1980s, liquid-liquid separation has become popular due to the relevant application area in the oil industry. This work is focused on liquid-liquid separation, specifically for a lighter dispersed phase. However, a brief review of solid-liquid hydrocyclones is imperative for understanding the principle of operation of this device and the evolution of the different models. It is important to stress up-front what are the main differences between these two types of separation processes. The density difference is much smaller for liquid-liquid mixtures, making the separation more difficult and creating the necessity of operating with higher centrifugal forces. The solid particles can be considered rigid unlike the liquid droplets which deform with the interaction of external forces. If high shear stress is present, this may cause droplet break up, reducing the probability of the smaller droplets to be separated. On the contrary, if two droplets get close enough, 9 coalescence may occur, whereby the resulted larger droplets can be separated more easily.

Disposal piles and skimmer tanks can remove a minimum drop size ranging 100-150 µm (Stewart and Arnold, 2008; Trambouze, 2002). The function of this kind of equipmentis to cause the oil droplets, which are dispersed in the water continuous phase, to separate and float to the surface to be removed. The two basic phenomena that are involved in the design are settling and coalescence. The more recent technologies uses gas flotation for settling improvement (Man et al., 2005; Lee et al, 2007), but air pumps need maintenance and energy supply. Turbulence can disperse drops or caused emulsion so it must be avoided (Stewart and Arnold, 2008). Settling is relatively well described and understood in the context of Stoke’s law: the smaller the droplets of the dispersed phase the more difficult phase separation becomes (Çengel and Turner, 2001). Coalescence is less well understood, as it is often driven by chemical interactions on interfaces of the dispersed droplets: bringing two droplets into contact does not automatically guarantee their coalescence (Billingham, 1992). Skimmers require substantial retention time for acceptable performance and efficiency downs for heavy oil or emulsions loads. There has been a shift within the overall industry to improve the basic designs including internal structures or distribution nozzles to encourage the coalescence of oil droplets within the tank. Among those, include tangential nozzle entry to promote swirling and oil droplet coalescence along the sides of the tank (Stall, 1981), as well as internal baffles or small hydrocyclones within the tank. The inlet design become crucial to provide a more uniform flow on entry to the tanks (Lee and Frankiewicz, 2005). For example, momentum breakers such as impingement and baffle plates or turbine-vane arrangements are routinely installed in the separators (Zhang et al., 2007; Hansen, 2005; Wilkinson et al. 2000; Jeelani and Hartland, 1998). The residence time distribution (RTD) is a concept which may be used to describe the flow behavior of the mixtures in the separator (Jaworski and Meng, 2005). Although the mean residence time (MRT) cannot be far from the theoretical residence time (TRT), the RTD is crucial to know the tank behavior (Simmons et al., 2002; Simmons et al., 2004). In this paper, numerical and experimental RTD are obtained for two typical skimmer tanks. For experimental data, a pilot plant facility was made and salinity pulse methodology was applied to know the RTD. As regards numerical data, CFD studies using scalar transport (euler-euler) and particle transport (euler-lagrangian) methods were performed. The minimum residence time, which is the elapsed time after the first particles (or the salinity pulse) was detected at the outlet.

2.1 Experimental Studies There are many references on oil-water separation hydrocyclone studies. Only a representative sample of these studies will be summarized here. The review is divided into laboratory studies and design and application studies, as follows. Laboratory Studies: Simkin and Olney (1956) worked with a conical hydrocyclone for the separation of coarse two-phase dispersion (droplet diameter > 1 mm). Sheng et al. (1974) investigated the performance of a conventional hydrocyclone. The effect of the material of construction of the hydrocyclone on the separation efficiency was also tested. Johnson et al. (1976) studied the ability of two small cyclones to separate Freon drops from water. Utilizing a theory developed for solid-solid extraction, they developed a correlation based on droplet size distribution to predict liquid-liquid separation efficiencies. Smyth et al. (1980) used a 30 mm-hydrocyclone to remove water from light oils. This hydrocyclone was able to reduce finely dispersed water concentrations of about 13% at the inlet to well below 1% and droplet size around 40 microns. Colman et al. (1980) carried out experimental work on a series of hydrocyclones, designed to remove small amounts of finely distributed oil from water. Colman and Thew (1980) introduced a coaxial outlet, which allowed increasing the concentration of oil at the inlet, improving the separation efficiency. Colman and Thew (1983) showed that for concentrations lower than 1% of oil the migration probability curves are independent of the operating split ratio. 11 A general revision of the hydrocyclone developed at Southampton University was carried out by Thew (1986), who also discussed some issues presented previously by Moir (1985). Gay et al. (1987) presented results of laboratory work, conducted on static conical cyclone and on a rotary cylindrical cyclone scale model. Field data were also presented for flow rates between 900 and 3750 BPD. The cylindrical cyclone gave better results for inlet oil concentration of about 0.1%. Thew (1996) discussed the influence of gas to remove free oil from water for concentrations less than 1%. Excessive shear caused droplet break-up and nullified separation. He concluded that for efficient separation the overflow stream should not exceed more than a few percent of feed. Bednarski and Listewnik (1988) presented a hydrocyclone design, for simultaneous separation of less dense liquid dispersion and solids, for concentration of oil between 2% to 5%. The authors observed an influence of the inlet diameters on the separation efficiency. They suggested that smaller inlets cause break-up of droplets, while the larger ones do not produce a swirl of sufficient intensity required for efficient separation. Woillez and Schummer (1989) designed and tested a rotary cylindrical cyclone (60 mm diameter) for cleaning water, with inlet oil concentration up to 0.1% and flow rates up to 65 gpm. They developed a correlation to predict efficiency behavior as a function of the droplet size distribution. An air-sparged hydrocyclone, consisting of a vertical cylinder having a porous wall, a conventional cyclone header, and a froth pedestal located at the bottom of the porous cylinder was tested by Beeby and Nicol (1993). An emulsion, with an oil concentration around 0.04%, was fed tangentially to develop a swirling flow. Air was sparged through the cylinder wall and it was sheared into small bubbles by the swirling 12 flow. The flocculated emulsion droplets in the waste water stream collided with these bubbles, and after attachment, they were transported into a froth phase. Efficiencies higher than 90% were reported. Young et al. (1990) measured the flow behavior in a 35-mm hydrocyclone, designed by Colman and Thew (1980), and compared the results with a new modified design developed by them. They studied the effects of operational variables and geometrical parameters, such as inlet size, cylindrical diameter, cone angle, straight section length, flow rate, and droplet diameter on the separation efficiency. They found that droplet diameter, differential density and cylindrical section length have significant impact on the separation process. Syed et al. (1994) studied the use of low-capacity mini-hydrocyclones (10 mm diameter) used in series, with feed rates less than 5 liters/minute, to improve the purification of produced water. Oil concentration at the inlet was between 0.03% to 0.08%. In 1991, Weispfennig and Petty explored the flow structure in a LLHC using a visualization technique (laser induced fluorescence). Different types of inlets were studied including an annular entry. A parameter that measures the intensity of the swirling flow, the Swirl Number, was used to characterize most of the results. This is defined as the ratio of the axial flux of the axial component of angular momentum to the axial flux of the tangential component of angular momentum. Vortex instability and recirculation zones were strongly dependent on the Swirl Number and a characteristic Reynolds Number. The performance of a small hydrocyclone was summarized by Ali et al. (1994). Deoiling hydrocyclones of 10 mm-diameter have achieved high performance 13 with cut size as low as 4 microns. The cut size (d50) is the particle size which has a 50% chance of being separated. Design and Applications: A summary of the selection, sizing, installation and operation of hydrocyclones was provided by Moir (1985). Meldrum (1988) described the basic design and principle of operation of the de-oiling hydrocyclone. Additionally, he presented test results for the first full-scale commercial application of the offshore fourin-one hydrocyclone (60 mm diameter) concept. He worked with oil concentration at the inlet up to 14%. Choi (1990) tested a system of six hydrocyclones (35 mm diameter) operating in parallel for produced water treatment (PWT). The performance of three commercial liquid-liquid hydrocyclones (two static and one dynamic) in an oil field was evaluated by Jones (1993). He studied the effects of the operational variables such as driving pressure, flow rate, reject rate, droplet size, and rotational speed, on the oil removal efficiency. It was found that the dynamic hydrocyclone is more effective than static hydrocyclone. Ortega and Medina (1996) used a small hydrocyclone for sludge thickening of domestic waste-water. They studied the effect of pressure drop and underflow diameter on the efficiency. 2.2

2.2 Modeling and CFD Simulations

Although widely used nowadays, the selection and design of hydrocyclones are still empirical and experience based. Even though quite a few hydrocyclone models are available, the validity of these models for practical applications has still not been established (Kraipech et al., 2000). A thorough review of the different available models can be found in Chakraborti and Miller (1992) and Kraipech et al. (2000). 14 Modeling: The LLHC models can be divided into empirical and semi-empirical, analytical solutions and numerical simulations (Chakraborti and Miller, 1992). The empirical approach is based on development of correlations for the process key parameters, considering the LLHC as a black box. The semi-empirical approach is focused on the prediction of the velocity field, based on experimental data. The analytical and numerical solutions solve the non-linear Navier-Stokes Equation. The former one is a mathematical solution, which is achieved neglecting some of the terms of the momentum balance equation. The numerical solution uses the power of computational fluid dynamics to develop a numerical simulation of the flow. As Svarovsky (1996) comments, it seems that the analytical flow models have been abandoned in favor of numerical simulations due to the complexity of the multiphase flow phenomena. Based on the experimental data taken by Kelsall (1952) using an optical method, many researchers have attempted to correlate the velocity field in the hydrocyclone, especially the tangential velocity. It can be determined using the following relationship (Kelsall, 1952, see also Bradley and Pulling, 1959): W r Constant n = (2.1) This implies that the tangential velocity (W) increases as the radius (r) decreases for positive values of the empirical exponent (n). The exponent, n is usually between 0.5 and 0.9 (Svarovsky, 1984) in the outer vortex, while in the core region it is close to -1 (see Figure 2.1). If n = 1 a free vortex is obtained where a complete conservation of angular momentum is implied or no viscous effect is considered. However, if n = -1 a forced vortex or a solid body rotation type is expected. Also, Kelsall's results are an evidence of the low dependence of the tangential velocity on the axial position.

CFD Simulations: Numerical simulations or CFD are used widely to investigate flow hydrodynamics. Erdal (2001) proposed a Mantilla (1998) modified correlation for the swirl intensity within the GLCC, based on extensive CFD simulations using the commercial code CFX (1997). As expressed by Hubred et al. (2000), the solution of the Navier Stokes Equations for simple or complex geometry for non-turbulent flow is feasible nowadays. But current computational resources are unable to attain the instantaneous velocity and pressure fields at large Reynolds numbers even for simple geometries. The reason is that traditional turbulence models, such as k-є, are not suitable for this complex flow behavior. On the other hand, more realistic and complicated turbulence models increase the computational times to inconvenient limits. 18 The flow in hydrocyclones has been numerically simulated by Rhodes et al. (1987). A commercial computer code was used to solve the required partial differential equations which govern the flow. Prandtl mixing-length model was used to account for the viscous momentum transfer effect. In a further work, Hsieh and Rajamani (1991) (see also Rajamani and Hsieh, 1988; Rajamani and Devulapalli, 1994) used a modified Prandtl mixing-length model with a stream function-vorticity version of the equation of motion. Good agreement with experimental data was observed in this study. The authors mentioned that the key for success is choosing the appropriate turbulence model and numerical solution scheme. He et al. (1997) used a three-dimensional model, with a cylindrical coordinate system and curvilinear grid, for the calculation of the flow field. A modified k-є turbulence model was proved to achieve good results. In most of the work reviewed in the previous paragraph, excluding Rhodes et al. (1987), the models were evaluated through comparison with laser-doppler anemometry (LDA) data. LDA has many advantages over other techniques. It is not as tedious as the optical technique and does not cause flow distortion like the Pitot tubes (Chakraborti and Miller, 1992). Many researchers have used this technique to measure the velocity field and turbulence intensities (Dabir, 1983; Fanglu and Wenzhen, 1987; Jirun et al., 1990; Fraser and Abdullah, 1995 and Erdal 2001). The literature review confirms the need for accurate experimental data utilizing appropriate sampling procedure and including the measurements of the droplet size distributions at the inlet and underflow sections, and the need to develop a simple mechanistic model for the LLHC. These deficiencies are addressed in the present study.

CONCLUSIONS AND FUTURE WORK

- In this work numerical simulation was performed of pilot oil skimmer tank. CFD results were in good agreement with experimental ones(literatures. However, the suitability of the numerical tools to study residence time was assessed. Velocity magnitude, pressure contours & vectors shows flow characteristics that help to understand and verify the main vortex structures found by CFD. Based on these simulation he following conclusions were reached:
- Perforate baffles model have more residency time when compared with simple baffle model, its almost double the time.
- Heavy density particle were settle down on the floor of the oil tank due to long residency time. Sot hat Perforate baffles model is very much suitable for separating the density fluids like oils.

Future work will be devoted to improves the agreement between numerical and experimental results for internal tanks. Additionally, others technologies like vortex flow tanks and coalescence tanks will be studied both experimentally and numerically.

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