Journal of Applied Fluid Mechanics, Vol. 12, No. 4, pp. 1037-1045, 2019.
Available online at www.jafmonline.net, ISSN 1735-3645, EISSN 1735-3645.
DOI: 10.29252/jafm.12.04.29318

Numerical Analysis of a Two-Phase Flow (Oil and Gas) in a Horizontal Separator used in Petroleum Projects

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(Received June 27, 2018; accepted November 27, 2018)

ABSTRACT

In the present paper, two-phase three-dimensional turbulent flow simulations are carried out by applying computational fluid dynamics (CFD) technique to the internal flow of a horizontal separator that is used in petroleum industry. Two different geometries are considered; the separator with a straight plate at the top and the separator with the straight plate on the side of the separator. Effects of the location, distance between the inlet of the separator and the diverter plate and inlet velocity on the separation efficiency are investigated by employing the standard k- ε turbulence model. For these purposes, three different distances between the straight diverter plate and the inlet to the separator (0.1 m, 0.15 m and 0.2 m) and four different velocities (0.25 m/s, 0.5 m/s, 0.75 m/s, and 1 m/s) are taken into account by means of Euler mixture model. It is revealed that the maximum separation efficiency is 99.772% when the mixture enters the separator from the top with the inlet velocity of 0.25 m/s and the plate is located 0.2 m away from the inlet section of the separator. An inverse correlation is detected between the inlet velocity and the efficiency of the separation since increasing the inlet velocity decreases the efficiency of the separation.

Keywords: Computational fluid dynamics (CFD); Horizontal separator; Two phase flow; Phase separation.

NOMENCLATURE

API	American Petroleum Institute
CFD	computational fluid dynamics
F	external body force
$\vec{F}_{lift,q}$	lift force
$\vec{F}_{vm,q}$	virtual mass force
g	gravitational acceleration
K	constant
L	distance between the inlet section of the separator and the diverter plate
m	mass flow rate
$\dot{m}_{pq}$	mass transfer from the pth to qth phase
$\dot{m}_{qp}$	mass transfer from the qth to pth phase
P	pressure shared by phases
VOF	volume of fluid
$\vec{R}_{pq}$	interaction force between phases
SIMPLE	semi-Implicit Method for Pressure linked Equations
$\vec{v}_q$	velocity of phase
Va	maximum allowable superficial velocity through the secondary separation section
$\vec{v}_{pq}$	interphase velocity
3D	three-dimensional
λ_q	bulk viscosity of phase q
μ_q	shear viscosity of phase q
ρ	density
τ	stress tensor
$\overline{\overline{\tau}}_q$	q^{th} phase stress-strain tensor

1. INTRODUCTION

Separators are vessels used in the petroleum facilities to decompose the crude oil that is taken out from the reservoirs into its components because the crude oil cannot be used directly without further processing. Once crude oil is drilled from the reservoirs it is processed and then send to either to any storage or to a refinery. As shown in Fig. 1 a separator is usually the first equipment through which the crude oil is processed and followed by other equipment such as heaters and exchangers, etc. It was reported that the oil separators affect the capacity of the whole petroleum facilities, Laleh *et al.* (2012). Separation of oil from other substances such as water and gas is a very important process in the petroleum industry. The separation process is defined as the decomposing of the mixed fluids into the gas, oil and water by means of separators, Arnold and Steward (1999).

Separating the crude oil into gas free-liquid and liquid-free gas is the aim of the best separator design and selection (Wilkinson *et al.*, 2000). Based on their functions, separators can be categorized as the two-phase separator and three-phase separator. The majority of two-phase separators are employed for separating the gas and oil. Depending on the particular needs of the well field, separators are designed in various shapes such as spherical, vertical and horizontal Laleh *et al.* (2011). Among these designs, separating gas and oil mixtures with the high gas-oil ratio, the horizontal separators are broadly employed. Figure 2 demonstrates the schematic view of a common horizontal gravity separator in which the incoming mixture to the separator impinges on the plate diverter that is situated a bit far away from the inlet. The mixture loses its momentum because of the impingement and as a result of the gravitational impact most of the oil droplets settle down while some of them and gases continue streaming together. Therefore, it can be concluded that the plate diverter has a significant role on the process of separation. Density difference between the components of the mixture is the main principle in separating process. This difference permits stratifying the constituents as moving gradually with liquid on the bottom and the gas on the top, solids like sands settle down in the base of the separator Abdulkadir and Hernandez-Perez (2010) since the phase with lower density raises as the one with higher density falls due to the existence of the gravity.

There are few corporate and public studies on the two-phase separators in the relevant literature. Some of them address operating performance associated with multiphase separators Zhang *et al.* (2007), Liu *et al.* (2017) while the others suggest separator design guidelines, Engineering Design Guidelines (2011). In comparison with the vertical separators, the horizontal separators have been studied extensively, due to the fact that these types of separators have much more advantages than the vertical separators. First of all, they are more economical than the vertical separators and enable better operation process since they provide larger area and longer distance between the inlet and outlets of the separator resulting in better settling and gas breakout Arnold and Steward (2008). The horizontal separators are also the most effective for high capacity processing as big quantities of gas in the liquid phase GPSA Engineering Data Book (1998). Effects of several design options such as inlet distributors and distributing baffles to minimize the volume and weight of a separation tank were reviewed by Frankiewicz *et al.* (2001) and Frankiewicz and Lee (2002). It was reported that, in addition to the design parameters, inlet speed of the mixture and size of the droplets have great influences on the separation efficiency and non-uniform liquid flow across the separator's cross-section could be induced by inlet designs with a substantial area of recirculation in order to that both phases governed a limited range of retention times. The design of the separators was based on the designers' experience and know-how gathered from experimental and/or simple empirical correlations Kirveskari (2016). Although experimental studies performed in the laboratories provide more accurate and real-like results they are time-consuming and expensive to deal with. As an alternative approach semi-empirical methods may be used, however, due to their some fundamental weaknesses a third method called CFD, has extensively been utilized in the industry due to the fact that it offers modeling the flow inside complex geometries and evaluating the results. Detailed knowledge of CFD based studies for large-scale separators can be found in the open literature Laleh *et al.* (2011). Such a CFD study was performed for a three-phase separator by the expansion of two-fluid model, Hallanger *et al.* (1996). Oil containing dispersed water, free gas and free water were the phases in the study in which the mixture model applied for modeling the oil phase. Outcomes of the study demonstrated that while almost all of the biggest globules might be combined with the free water phase, most of the smallest water globules might persist in the oil phase. Separation phenomenon within two different three-phase horizontal gravity separators were investigated by means of CFD technique. It was showed that in comparison with semi-empirical approaches CFD can offer powerful guidelines, Ghaffarkhah *et al.* (2017). Using an in-house CFD code it was reported that both physical and chemical phenomenon are important in various zones of a three-phase separator, Hansen *et al.* (1991). Hydrodynamics of a mixture flowing through a three-phase gravity separator with the side positioned inlet pipe was mathematically investigated by API design criteria. The separation process was controlled by proper-integral (PI) control loops, Sayda and Taylor (2007).

As aforementioned, there are few studies dealt with the efficiency of the separators, however, none of them have investigated the appropriate position of the diverter plate in a horizontal separator with the top and side inlet pipes. The present study, therefore, aims to fill the gap in the relevant literature by considering the effects of different parameters such as the inlet velocity, the distance

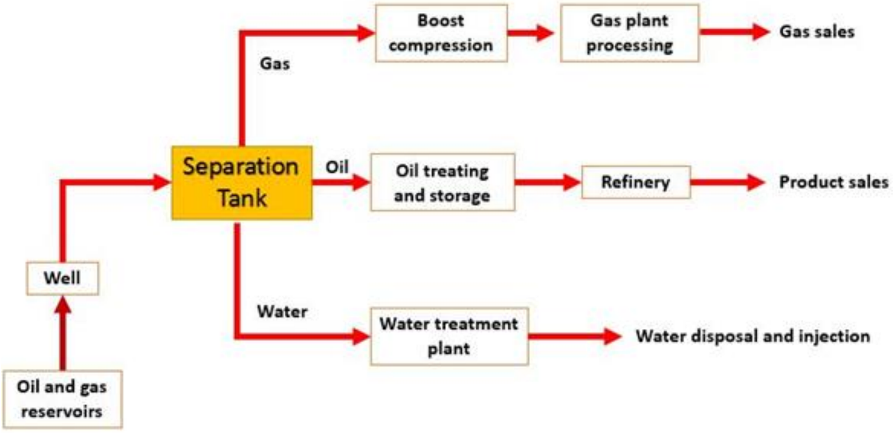

Fig. 1. Schematic representation of gas-oil and liquid production.

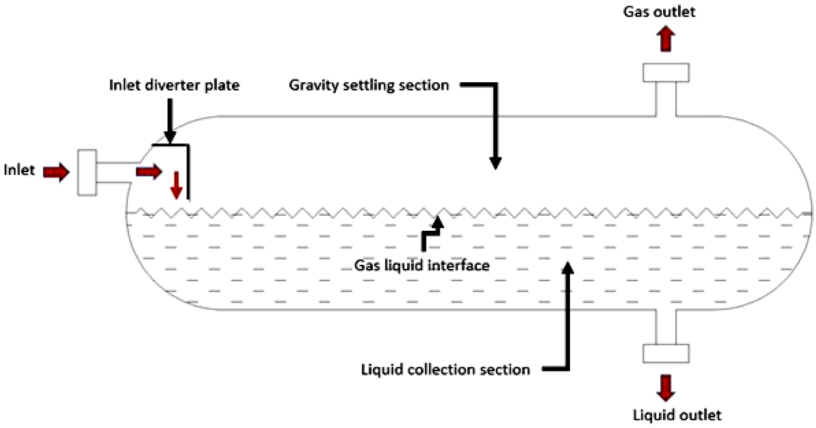

Fig. 2. A typical horizontal two-phase separator.

between the diverter plate and the inlet of the separator and the position of the pipe in which the mixture enters the separator.

2. COMPUTATIONAL MODEL

In the present study, the influence of the geometric parameters such as the distance between the inlet of the separator and the diverter plate and the position of the inlet (top/side arrangements) and the inlet velocity on the separation efficiency is investigated numerically without considering any external forces to boost the separation process. As indicated in the relevant literature, these are the most important aspects of the design process of a separator, Ghaleni *et al.* (2012). In this section, the physical model including the dimensions of the separator and diverter plates for the separator with top and side inlets, mesh structure, boundary conditions and governing mathematical equations are presented.

The separation of the mixed fluids is driven by the density differences between the phases. The phase with the lower density raises as the one with higher density falls due to the existence of the gravity. In the simulation of any engineering fluid flow problem, the generation of the flow geometry is the first stage. In the present study, a 3D model of a two-phase (gas phase-oil phase) horizontal separator is generated and then analyzed under steady flow condition. The computational domain consists of a cylindrical separator with one inlet pipe and two outlet pipes. The length and diameter of inlet pipe and outlet pipes are 1 m and 0.1 m, respectively while the height and length of the separator are kept constant as to be 0.9 m and 3 m for both arrangements (separator with side inlet and top inlet). As it is shown in Fig. 3, diverter plate is 0.3 m in length and 0.27 m in width. Effects of the distance between the inlet section of the separator and the diverter plate (L) are studied for three different distances; 0.1 m, 0.15 m, and 0.2 m.

Velocity inlet boundary condition is applied to the pipe where the mixed fluids enters to the separator while oil and gas outlets are set to outflow (Fig. 4). The no-slip condition is applied to the surfaces of the diverter plate, separator and pipes. Simulations are initialized by defining uniform inlet velocity magnitudes as 0.25 m/s, 0.5 m/s, 0.75 m/s and 1 m/s, turbulence intensity (4.5%) and hydraulic diameter (0.1 m).

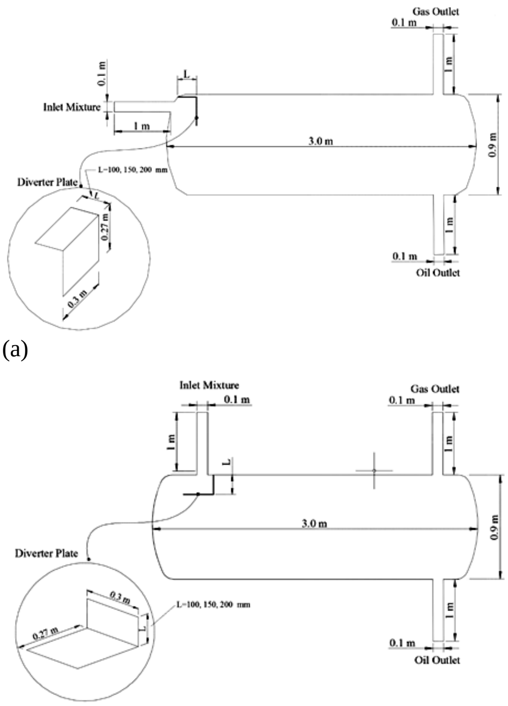

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Fig. 3. Geometry and dimensions of two different separator arrangement a) separator with side inlet pipe, b) separator with top inlet pipe.

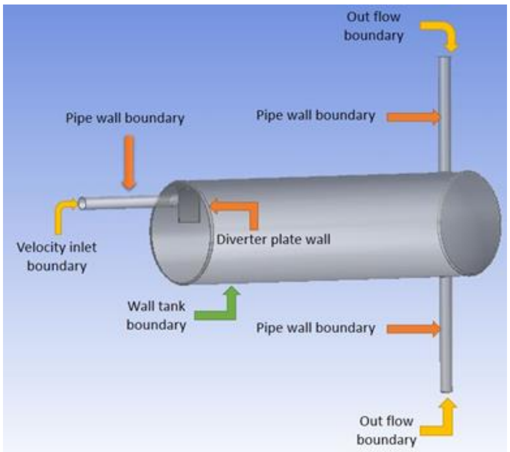


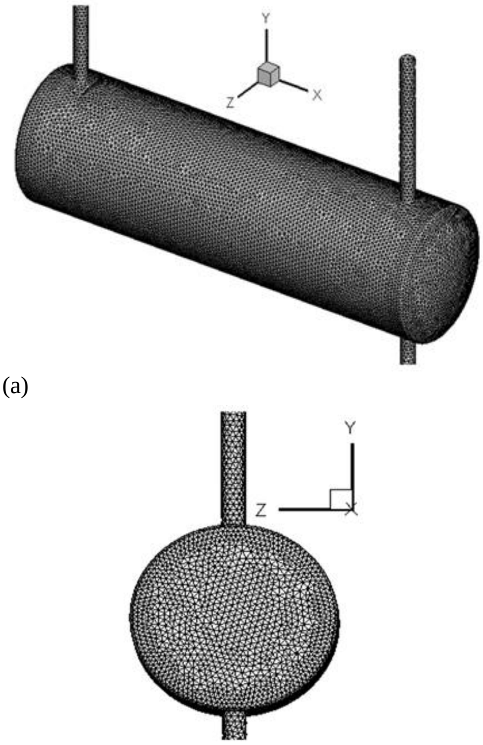
Fig. 4. Boundary conditions applied to the model.

The density and viscosity values of the fluids used in the present study are given in Table 1.

Table 1 Properties of the fluids used in the study

Fluid	Density (kg/m^3)	Viscosity (kg/ms)
Gas	60.8	1.2×10^{-3}
Crude oil	825	0.00237

Computational domain is split into several small volumes called mesh elements that may be structured or unstructured. It was reported that, in most cases, using structured mesh elements provide faster solution and more accurate results, however, they cannot be generated easily for complex geometries, Bono and Awruch (2007). Since the computational domain in the present study is a combination of three cylindrical pipes as one inlet and two outlet pipes and a cylindrical separator with rectangular diverter plate the non-uniform triangular mesh elements are generated that enable using the smaller and denser elements in the regions where sharp gradients are expected such as the intersection of the pipes and separator as shown in Fig. 5.



(a)

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Fig. 5. Mesh elements used on the separator a) perspective view, b) cross-sectional view.

To establish the accuracy of the solution and keep the computational costs low a mesh independence study is conducted with several unstructured mesh elements called coarser (201248 elements), coarse (310233 elements), normal (423396 elements), fine (526778 elements), the finer (684902 elements) and the finest mesh (800000 elements) before performing further analyses. As shown in Fig. 6, the difference between the numerically estimated and the ideal efficiencies (100%) decreases by using more mesh elements. Increasing the number of mesh elements to 423396 from 310233 (coarse mesh) affects the calculated efficiency with 2.2% error while it deviates only 1.4% when using 526778 elements (fine mesh) instead of normal mesh. Although the minimum error is obtained with the finest mesh to keep the computational cost low, the further analyses are done with the finer mesh due to the fact that the difference between the finer and the finest meshes is negligible.

It was reported that volume of fluid (VOF), Eulerian-Lagrangian (E-L), Eulerian-Eulerian (E-E) and mixture modeling are available for multi-phase flows, Madhavan (2005). When compared to each other, it can be seen that each approach has some specific advantages and disadvantages. For example, the E-L approach deals with the continuous fluid phase as a continuum by solving Navier-Stokes equation, while the dispersed phase is solved by following lots of droplets through the flow-field as a function of both space and time. However, the E-E approach considers the several phases as continuous that are interacted with each other, Ghaffarkhah *et al.* (2017). In the E-E approach, the volume for one phase cannot be filled by the other phases, phase-to-volume fractions are continuous functions of space and time. The sum of both fractions is equal to 1. In the present paper, the E–E approach is adopted due to its robustness, Kirveskari (2016). The steady flow of mixed fluid through the computational domain is solved by continuity (Eq. (1)) and momentum (Eq. (2)) equations.

$$\nabla.(\alpha_q \rho_q \overrightarrow{v_p}) = \sum_{p=1}^{n} (\dot{m}_{pq} - \dot{m}_{qp}) \tag{1}$$

$$\nabla.(\alpha_q \rho_q \vec{v}_q \vec{v}_q) = -\alpha_q \nabla p + \nabla \bar{\bar{\tau}}_q + \alpha_q \vartheta_q \vec{g} \tag{2}$$

$$\sum_{p=1}^{n} (\vec{R}_{pq} + \dot{m}_{pq} \vec{v}_{pq} - \dot{m}_{qp} \vec{v}_{qp}) \tag{3}$$

where

$$\begin{aligned} \bar{\bar{\tau}}_q &= \alpha_q \mu_q (\nabla \vec{v}_q + \nabla \vec{v}_q^{\,T}) + \\ &\alpha_q (\lambda_q - 2/3 \mu_q) \nabla \vec{v}_q \bar{\bar{I}} \end{aligned} \tag{4}$$

$$\sum_{p=1}^{n} \vec{R}_{pq} = p = 1 \sum^{n} K_{pq} (\vec{v}_p - \vec{v}_q) \tag{5}$$

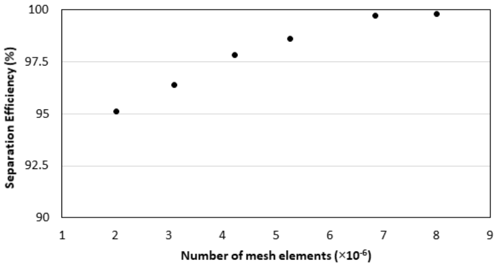


Fig. 6. Mesh independence study.

The individual momentum equation for every phase is solved by the Eulerian model that can be joined with suitable multiphase turbulence model, Kharoua *et al.* (2013). During the simulations the oil is defined as the second phase while the gas is assumed to be the continuous phase. The k-ε turbulence model is used because it was reported that it is robust, simple and reasonable low computational cost, White (1997). The separation efficiency is calculated as given in Eq. (6), Arntzen (2001).

$$\eta = 100 \times \left(\frac{m_{oil,inlet} - m_{oil,gas}}{m_{oil,inlet}} \right) \tag{6}$$

where $m_{oil,gas}$ is the oil content in gas outlet. The governing equations are solved using a finite volume based method according to the phase-coupled SIMPLE since it provides reduced calculation time and better convergence. First order upwind scheme for spatial discretization of the momentum, volume fraction, turbulent kinetic energy and the dissipation of the turbulent kinetic energy are used.

3. MAIN FINDINGS AND DISCUSSION

In this part of the paper, the results of a comparison are presented to show the validity of this numerical study. To that end, the computational results are compared with the data found in the open literature, Efendioglu *et al.* (2014). The comparisons are made for two different distances between the inlet of the separator and the diverter plate when the inlet pipe is positioned to the side of the separator. As shown in Fig. 7, the difference between two studies is 0.5% and 0.1% when the distance between the inlet of the separator and diverter plate is L=0.1 and 0.17 m, respectively.

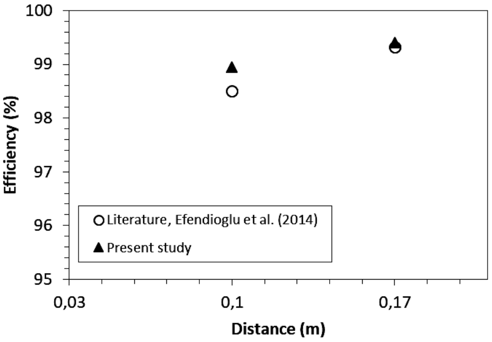


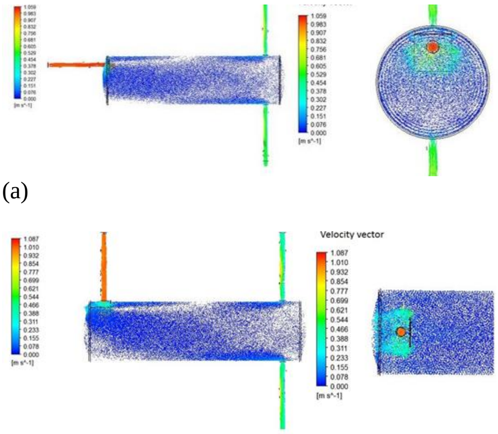
Fig. 7. Validation of the present study.

Furthermore, the maximum gas velocity through the separation section of the separator investigated in the present study is compared with the API standards on the oil and gas separators, API (2008) where the maximum allowable superficial velocity of a gas at operating conditions can be calculated by Eq. (7).

$$V_a = K(\rho_{liqued} / \rho_{gas})^{1/2} \tag{7}$$

It is checked that the magnitude of the average gas velocity through the secondary separation section of the separator under investigation is not higher than the velocity calculated by Eq. (7).

Velocity vectors of the mixture flowing with V=1 m/s through the separator with the side and top inlets for L=0.1 m is given in Fig. 8. It can be seen that the mixture issues from the inlet and impinges on the diverter plate with very high velocity. Following the impingement, the velocity of the mixture decreases gradually and the flow direction changes and most of the fluid is diverted downward in the separator. Due to the impact of gravity the oil settles down as presented in Fig. 9. Then, the gas flows towards the outlet of the pipe with a lower velocity. Actually, such a low velocity is desirable to get the enough retention time for the oil droplets. It also allows the downfall of the oil. This outcome agrees well with the literature Arnold and Steward, 1999; Wilkinson *et al.*, 2000; Laleh *et al.*, 2011.

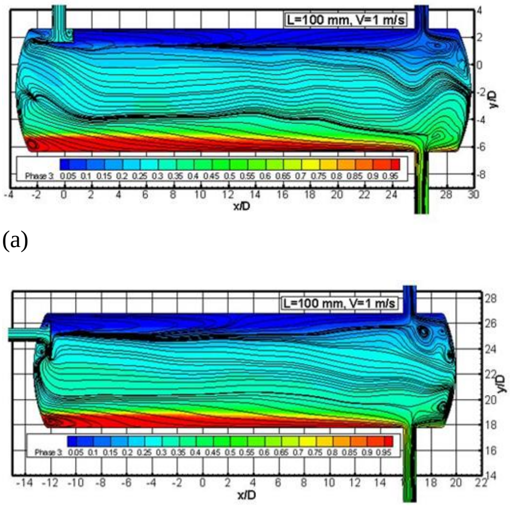


(a)

(b)

Fig. 8. Velocity vectors of the mixture flowing through the separator with a) side inlet and b) top inlet. L=0.1 m, V=1 m/s.

Figure 9 reveals the streamlines of the oil within the separator with the top and side inlets. At the beginning, as the mixture enters the circular separator, the velocity of the mixture increases a bit and the oil moves downward the separator while the gas attempts to move upward the top of the separator (Fig. 10). The formation of the swirl stream and then vortex impacts the separation efficiency. When the vortex rises in the separator the efficiency of separation process decreases.

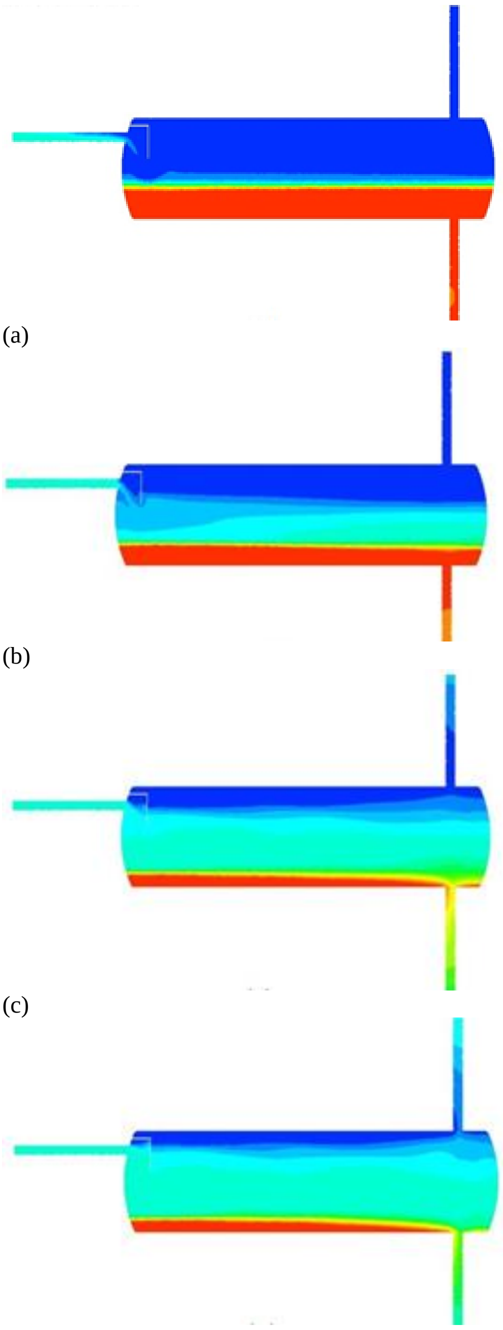


(a)

(b)

Fig. 9. Oil contours and the streamlines of the flow through the separator with a) top inlet and b) side inlet. L=0.1 m, V=1 m/s.

Volume fractions for oil are given in Fig. 10 for various inlet velocities at side inlet when the distance between the separator inlet and the diverter plate is L=0.2 m. It is seen that after the collision of the mixture with the diverter plate the layers of oil fraction change its color from red (represents oil phase) to blue (stands for gas phase) which means that the level of the oil decreases with increasing the inlet velocity. The intersection between these layers indicates a fluid mixture between oil and gas. When velocity of the mixture is 0.25 m/s, 0.5 m/s, 0.75 m/s and 1 m/s the separation efficiency is found to be 99.772% , 93.076%, 79.411% and 64.332% respectively. When the inlet velocity increases the region of mixture layers extends in the normal direction which indicates the lower separation efficiency. The similar result was indicated in the literature, Abdulkadir and Hernandez-Perez (2010).



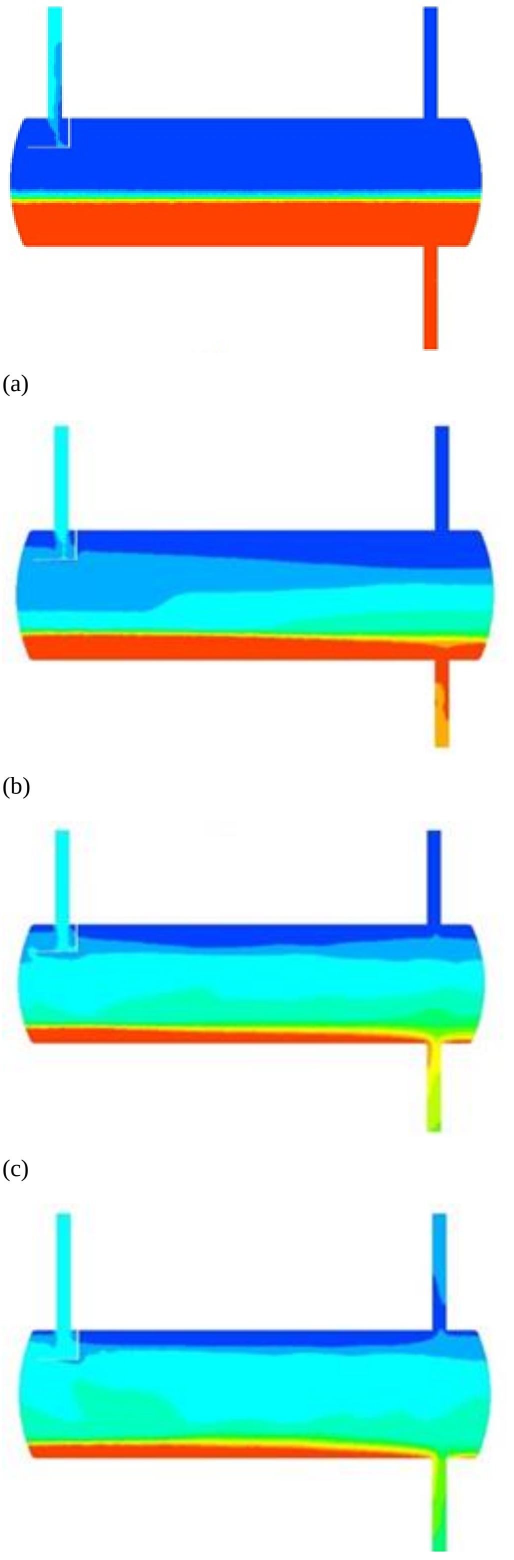
(a)

(b)

(c)

(d)

Fig. 10. Volume fraction of oil through the separator with the side inlet at a) V=0.25 m/s, b) V=0.5 m/s, c) V=0.75 m/s and d) V=1 m/s. L=0.2m.


(a)

(b)

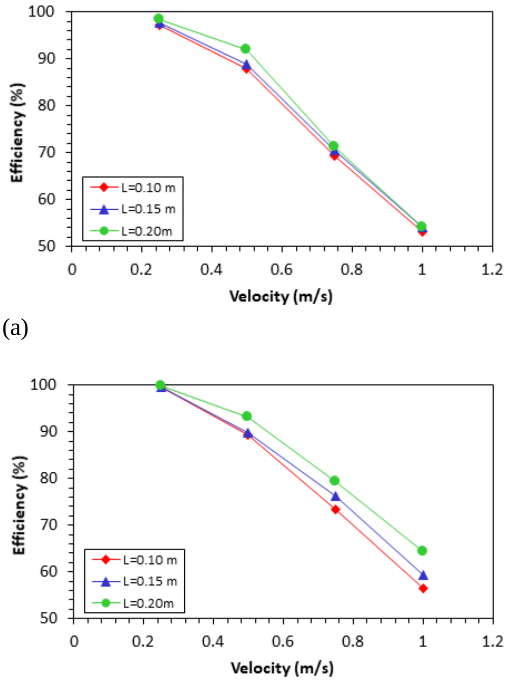
(c)

(d)

Fig. 11. Volume fraction of oil through the separator with the top inlet at a) V=0.25 m/s, b) V=0.5 m/s, (c) V=0.75 m/s, d) V=1 m/s. L=0.2 m.

Figure 11 shows the volume fraction of oil for when the pipe is located to the top of the separator. Such flow condition provides the separation efficiency as 98.317%, 91.916%, 71.287% and 54.182%, respectively when inlet velocity increases from 0.25 m/s to 1 m/s with 0.25 m/s increments. Comparing with the separator with the side inlet it can be concluded that using separator with the top inlet causes the separation efficiency drop a little bit.

Figure 12 presents a correlation between separation efficiency and the inlet velocity of the mixture flowing through the separator for various distances between the separator inlet and the diverter plate (L). It is obvious that regardless of the positions of the inlet pipes and the distance the separation efficiency decreases dramatically with increasing inlet velocity. For the separator with the side pipe, the separator efficiency decreases from 98.317% to 54.182% when the mixture inlet velocity increases from 0.25 m/s to 1 m/s at L=0.2 m whereas at the same distance the efficiency reduces to 64.332% from 99.772%. The plots reveal also that when the distance between the diverter plate and inlet section of the separator increases the efficiency of the separator increases in both configurations (side and top inlet). In comparison with the side inlet, the top inlet configuration provides higher separation efficiency at any distance. Change in the distance between the separator inlet and the diverter plate have higher effects on the separation efficiency of the separator with top inlet configuration.



(a)

(b)

Fig. 12.Change of separation efficiency with the inlet velocities for various distances a) side inlet configuration, b) top inlet configuration.

Change of the separation efficiency with the parameters under investigation such as inlet velocity, the distance between the diverter plate and inlet section (L) and side and top pipe configuration is given in Table 2. As aforementioned, the separation efficiency increases with the distance regardless of the inlet velocity and pipe configuration, however, it decreases with the inlet velocity at any pipe configuration. The highest mixture separation is obtained when the separator with the top inlet is used regardless of the inlet velocity and the distance.

Table 2 Separation efficiency shows at variable distance and velocity

Velocity (m/s)	Efficiency for the side inlet (%)		
	L=0.1 m	L=0.15 m	L=0.2 m
0.25	97.215	97.735	98.317
0.50	87.871	88.951	91.916
0.75	69.472	70.587	71.287
1.00	53.257	54.063	54.182
Velocity (m/s)	Efficiency for the top inlet (%)		
	L=0.1 m	L=0.15 m	L=0.2 m
0.25	99.605	99.688	99.772
0.50	89.409	89.911	93.076
0.75	73.520	76.219	79.411
1.00	46.415	59.362	64.332

4. CONCLUSION

The present paper reports the results of the effects of position of the inlet pipe in which the mixture enters to the separator and the distance between the inlet section of the separator and the diverter plate on the separation efficiency for various mixture inlet velocities by means of a series of two-phase (oil and gas) flow simulations. It is seen that separation efficiency increases with the distance of the diverter plate, however, decreases with the inlet velocity of the mixture due to the fact that low inlet velocity provides enough time for the retention of the oil in the separator as reported in the literature . In comparison with the separator with the side inlet using the separator with the top inlet provides the higher separation efficiency at any inlet velocity and the distance. The highest separation efficiency is obtained as 99.772% when the mixture enters the separator with the top inlet at 0.25 m/s and the diverter is located 0.2 m away from the inlet of the separator. However, such a high efficiency may decrease to 53.257% when the mixture enters the separator with the side pipe with 1 m/s and impinges on the diverter plate located that is 0.1 m away from the inlet.

REFERENCES

Abdulkadir, M. and V. Hernandez-Perez (2010). The Effect of Mixture Velocity and Droplet Diameter on Oil-water Separator using Computational Fluid Dynamics (CFD). WASET, *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering* 4 -1.

American Petroleum Institute (2008) Specification for Oil and Gas Separators, API Specification 12J, 8th Edition, October.

Arnold, K. and M. Stewart (1999). Surface Production Operations, Volume 2: Design of Gas-Handling Systems and Facilities. *Gulf Professional Publishing.*

Arnold, K. and M. Stewart (2008). *Surface Production Operations.* 3rd Edition, Elsevier.

Arntzen, R. (2001). *Gravity Separator Revamping*. A Thesis Submitted for the Degree of Dr.Ing. Department of Chemical Engineering Norwegian University of Science and Technology. Trondheim, Norway.

Bono, G. and A.M. Awruch (2007). Numerical Study between Structured and Unstructured Meshes for Euler and Navier-Stokes Equations. *Mecanica Computacional* 26, 3134-3146.

Efendioglu, A., J. Mendez and H. Turkoglu (2014). The Numerical Analysis Of The Flow and Separation Efficiency of a Two-Phase Horizontal Oil-Gas Separator With an Inlet Diverter and Perforated Plates. *Advanced Fluid Mech*anics, 10- 133.

Engineering Design Guidelines (2011), Separator Vessel Selection and Sizing, KLM Technology Group, April.

Frankiewicz, T. and C. M. Lee (2002). Using computational fluid dynamics (CFD) simulation to model fluid motion in process vessels on fixed and floating platforms. *In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers* 77494, 1-9.

Frankiewicz, T., M. M. Browne, C. M. Lee (2001) Reducing separation train sizes and increasing capacity by application of emerging technologies. *Offshore Technology Conference, Offshore Technology Conference*, 30 April-3 May, Houston, Texas.

Ghaffarkhah, A., M. A. Shahrabi, M. K. Moraveji and H. Eslami (2017). Application of CFD for Designing Conventional Three Phase Oilfield Separator. *Egypt. J. Pet.*, 26, 413-420.

Ghaleni, M. M., M. Zivdar, M. R. Nemati. Hydrodynamic Analysis of Two Phase Separator by Computational Fluid Dynamic (CFD), *The 6th International Conference on Advanced Computational and Experimenting*, 1-4 July 2012, Istanbul, Turkey.

GPSA Engineering Data Book (1998). Gas Processors Suppliers Association, Tulsa. OK.

Hallanger, A., F. Soenstaboe and T. Knutsen (1996). A Simulation Model For Three-Phase Gravity Separators. *In SPE Annual Technical Conference and Exhibition.* Society of Petroleum Engineers 36644, 695 –706.

Hansen, E. W. M., H. Heitmann, B. Laksa, A. Ellingsen, A.O. Ostby, T.B. Morrow and F.T. Dodge (1991). Fluid Flow Modeling of Gravity Separators. *5th International*

Conference on Multi-Phase Production, Cannes, France.

Kharoua, N., L. Khezzar and H. Saadawi (2013). CFD Modelling Of a Horizontal Three-Phase Separator: A Population Balance Approach. *American Journal of Fluid Dynamics* 3(4),101-18.

Kirveskari, L. (2016). *Design of Horizontal Phase-Separators Using Computational Fluid Dynamics*, MSc Thesis, Aalto University.

Laleh, A. P., W. Svrcek and W. D. Monnery (2012).Computational Fluid Dynamics-Based Study of an Oilfield Separator-Part I-A Realistic Simulation. *Oil Gas Facil.* 1(6), 57-68.

Laleh, P.A., W.Y. Svrcek and W.D. Monnery (2011). Computational Fluid Dynamics Simulation of Pilot- Plant- Scale Two- Phase Separators. *Chemical Engineering Technology,* 34 -2, 296-306.

Liu, Y., Y. Deng, M. Zhang, P. Yu and Y. Li (2017). Experimental Measurement of Oil-Water Two-Phase Flow by Data Fusion of Electrical Tomography Sensors and Venturi Tube. *Measurement Science and Technology*, 28, 095301 (15pp).

Madhavan, S. (2005). CFD Simulation of Immiscible Liquid Dispersions, Master's thesis, Halifax: Dalhousie University.

Sayda, A.F. and J.H. Taylor (2007). Modeling and Control of Three-Phase Gravity Separators in Oil Production Facilities. *Proceedings of the American Control Conference*, New York, NY, USA.

White, F. (1997). *Fluid Mechanics*. McGraw-Hill.

Wilkinson, D., B. Waldie, M.I.M. Nor and H.Y. Lee (2000). Baffle plate configurations to enhance separation in horizontal primary separators. *Chem. Eng. J.*, 77 - 221–226.

Zhang, L., H. Xiao, H. Zhang, L. Xu and D. Zhang (2007). Optimal Design of a Novel Oil-Water Separator for Raw Oil Produced from ASP Flooding. *Journal of Petroleum Science and Engineering* 213-218.