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Computational analysis of effects of location of the diverter plate and inlet velocity on the efficiency of two-phase flow separator

Ayrıştırma plakasının konumunun ve giriş hızının iki-fazlı ayrıştırıcı verimine olan etkilerinin sayısal analizi

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Ayrıştırma Plakasının Konumunun ve Giriş Hızının İki-Fazlı Ayrıştırıcı Verimine Olan Etkilerinin Sayısal Analizi

Araştırma Makalesi / Research Article

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ÖZ

İki fazlı yatay yerçekimsel ayrıştırıcılar petrol sektöründe genellikle petrol ve gazın birbirinden ayrıştırılması için kullanılırlar. İlgili literatürde ayrıştırıcının optimum çap ve uzunluğun belirlenmesi amacıyla çeşitli çalışmalar mevcuttur. Her ne kadar ayrıştırma plakası, ayrıştırma hızını arttırmak için kullanılmakta ise de, ayrıştırma plakasının akışkan giriş borusunun neresine yerleştirileceği konusunda kesin bir yaklaşım bulunmamaktadır.

Bu çalışmada ayrıştırıcının ana hacmi, kullanılan petrol ve gazın belirli bir karışım miktarı için tanımlanmıştır. Ayrıştırma plakasının konumu ve farklı hız değerlerinin ayrışma verimi üzerindeki etkileri, hesaplamalı akışkanlar dinamiği (HAD) metodu kullanılarak ayrıştırma plakasının üç farklı konumu (100 mm, 150 mm ve 200 mm) ve dört farklı giriş hızı (0,25 m/s, 0,5 m/s, 0,75 m/s ve 1 m/s) için incelenmiştir.

İki fazlı, üç boyutlu ve tam türbülanslı akış analizleri sonucunda, en iyi ayrışma verim değerinin yaklaşık %99 ile ayrıştırıcı plakanın, borunun üst noktasına 200 mm uzaklıkta ve karışımın sisteme giriş hızının 0,25 m/s olduğu değerde iken sağlandığını ortaya koymuştur.

Anahtar Kelimeler: Petrol gaz ayrıştırılması, iki fazlı akış, yatay ayrıştırıcı.

Computational Analysis of Effects of Location of the Diverter Plate and Inlet Velocity on the Efficiency of Two-Phase Flow Separator

ABSTRACT

Two-phase horizontal gravity separators are generally used in the petroleum industry for gas and liquid separation. There are several studies in the relevant literature that reports various methods to determine the optimum diameter and length of the separator. Although the diverter plate is used to increase the separation speed, there is not any exact approach for specifying the appropriate location of the diverter plate on the inlet pipe. In the present study, the main volume of the separator is defined for a particular amount of mixture of oil and gas. Effects of the location of the diverter plate and inlet velocity on the separation efficiency are investigated for three locations of the diverter plate (100 mm, 150 mm, 200 mm) and four different inlet velocities (0,25 m/s, 0,5 m/s, 0,75 m/s, 1 m/s) by means of computational fluid dynamics (CFD) method. Two-phase, three-dimensional (3D) and fully turbulent flow simulations reveal that the highest separation efficiency is obtained as 99% when the straight diverter plate is 200 mm far away from the top inlet and the inlet velocity is 0,25 m/s.

Keywords: Oil gas separation, two-phase flow, horizontal separator

1. INTRODUCTION

In the oil industry, the separator is a pressure vessel utilized to separate liquids extracted from gas and oil wells to liquid and gaseous constituents [1]. Separating the well flow into gas free-liquid and liquid-free gases is the aim of the best separator design and selection. In the ideal condition, liquid and gas attain a balance of state at the present conditions of temperature and pressure inside the vessel [2]. Heavy oil dissolved in water tends to remain dispersed due to the high reduction factors [3]. Oil droplets accumulate at the top of the pipeline because the density of oil droplets is lower than the density of water [4-5]. The density difference between components is the principle separators process. These differences permit stratifying the constituents as moving gradually with liquid on the bottom and the gas on top. Solids like sand settle down in the base of the separator as well. The mixed fluid extracted from gas and oil separated into gas, oil, and water [6-9].

Horizontal, spherical and vertical are the most common designs for building separators. When the volume of total

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liquids is obtainable and amounts of dissolved gas in it, horizontal separators are installed. Mainly, the procedure could be phase removal of gas, water, oil and possibly sand. Separation efficiency by reducing the size and designing the most appropriate separator is significant in the oil industry. Pressure fluctuations induced by two-phase gas-solid flow have been experimentally investigated in a large-scale cyclone separator [10].

The present paper exhibits a series of simulations for a horizontal separator by employing Euler-model. By this method, the two-phase flow behavior of a horizontal separator can be demonstrated.

1.1. Horizontal Separators

For elevated gas oil ratio (GOR) wells, horizontal separators are constantly employed. A horizontal two-phase separator is displayed in Figure 1. When the liquids enter the separator and hit the inlet diverter, it results in abrupt alterations in momentum at the inlet, the early gross separation of vapor and fluids happens. Because of the gravity force, the fluid droplets drop out of the gas flow to the vessel floor.

In addition to the traditional homogeneous model, a new liquid model is presented to obtain pressure gradient, retention and shear rate estimates in liquid-liquid distributions [11]. Generally, four main functional zones can be identified in a horizontal two-phase separator [12- 13]. The CFD model can be usefully used for the designing of interiors of off-shore three-phase separators, such as skid proof curtains and sluice [14- 15]. The primary separation zone, which is desired for separating the bulk fluid from the gas flow, is the section between the inlet nozzle and first baffle. The gravity settling zone is downstream from the primary separation zone. This section is utilized for entraining globules to settle from the wet gas stream. Normally, gravity settling zone resides a vast segment of the vessel volume during which the gas passes at a comparatively low velocity. The droplet coalescing zone is coming after the gravity settling zone. This section might be vane packs, parallel plates, spiral flow demisters, and mesh pads. Based upon impingement and inertial separation principles, the droplet coalescing zone assists in removing extremely tiny droplets.

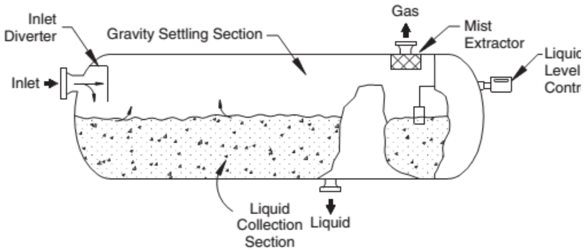


Figure 1. A typical scheme of a horizontal two-phase separator [4]

Table 1. Mesh independence study

Mesh Structure	Number of element	Separation efficiency	Difference (%)
Coarser	201248	95.1	4.9
Coarse	310233	96.4	3.6
Normal	423396	97.8	2.2
Fine	526778	98.6	1.4
Finer	684902	99.772	0.2

2. METHODOLOGY AND MATHEMATICAL MODEL

This study was performed by utilizing computational fluid dynamics (CFD) technique to reveal the influence of the change of geometric parameters like the distance between the inlet and plate diverter and position of the inlet top and side arrangements on the separation efficiency. Effects of inlet velocity were also investigated. These are the most important aspects of the design process of a separator as indicated in the literature [16-18]. In this section physical model including the dimensions of the separator and diverter plates for separator with top inlet and side inlet, mesh structure, boundary conditions applied to the simulations and corresponding mathematical equations are presented.

The present study demonstrates the results of a series of simulations of three dimensional (3D) model of a two-phase gas-oil horizontal separator under steady-state conditions. The separator under consideration has a length of 3 m and a height of 0,9 m while both inlet and outlet pipes are 1 m long. The inlet diverter plate has a length of 0.3 m, the width of 0.270 m. Three horizontal distances (100 mm, 150 mm, and 200 mm) were investigated to reveal its effect on the separator efficiency, (Fig.3).

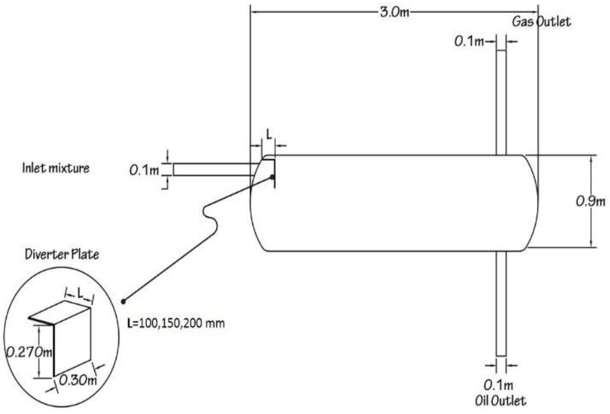


Figure 3. Dimensions of the horizontal separator under consideration

A working domain consists of inlet and both outlet pipes and the horizontal separator has meshed for simulations. As presented in Table 1, a mesh independence study was conducted with several mesh elements. It is seen that increasing the number of mesh elements decreases the difference between the calculated separation efficiency and the ideal efficiency (100%). The minimum difference was obtained with the finer mesh that contains 984902 elements, therefore, all the simulations were performed with the finer mesh as shown in Table 1.

As shown in Fig.4 relatively denser mesh elements were used towards the outer walls of the pipes and separator and also at the intersection of the lateral areas of the separator with the two ends of it. It was checked that the non-dimensional grid spacing (y+) for each velocity changes between 70 and 120.

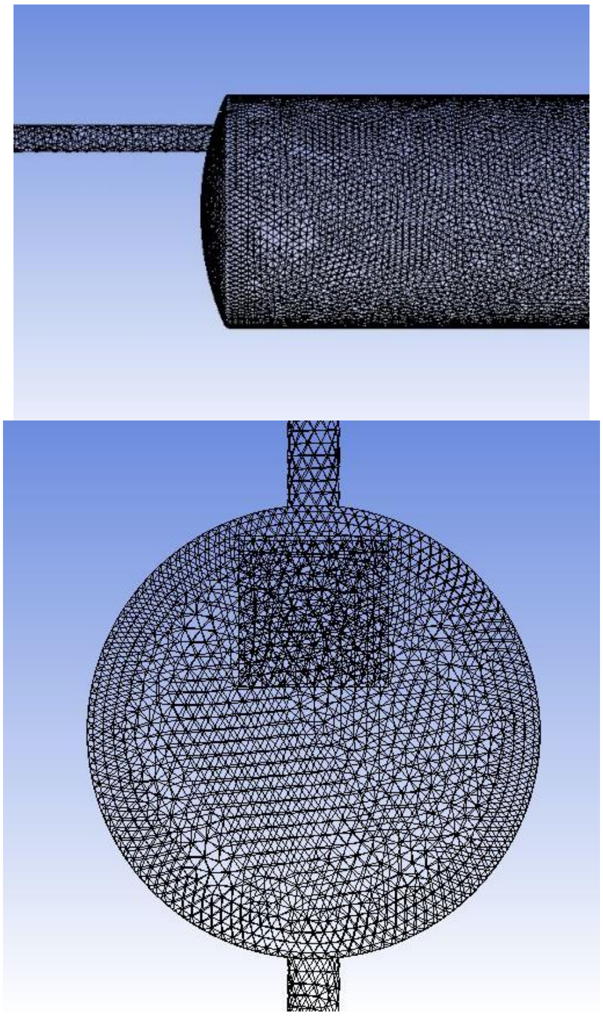


Figure 4. Mesh elements used on the separator

Figure. 5 shows the boundary conditions applied to the domain. The side inlet of the mixture to the pipe seen at the left side was specified as velocity inlet while the outlet of the pipes seen at top-right and bottom-right was set as outflow. At the inlet, both turbulence intensity (I) and hydraulic diameter were specified as 1% and 0,1 m, respectively. The turbulence intensity (I) is calculated as the function of the Reynolds (Re) number (Eq.1).

$$I = 0.16(Re_D)^{-0.25} \qquad (1)$$

The pipe lateral walls, the diverted plates as well as the separator walls were defined as wall type.

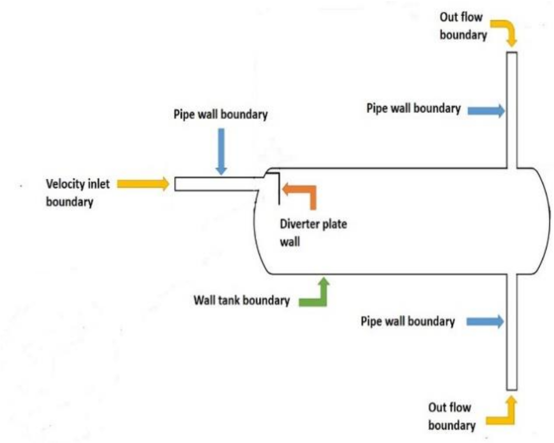


Figure 5. Boundary conditions applied to the horizontal separator

The gas was selected as the primary phase since the gas volume fraction was higher than in oil-gas mixture. Here, the oil was termed as a secondary phase. The density and viscosity of the oil and gas are assumed as to be 825 kg/m3, 60.8 kg/m3 and 0.00237 kg/ms and 0.000012 kg/ms, respectively.

The corresponding mathematical equations for the steady and incompressible flow are presented below where Eq.2 and Eq.3 show continuity and momentum equations, respectively, [19].

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (2)$$

$$\nabla \cdot (\rho \vec{v}\vec{v}) = -\nabla p + \nabla \cdot (\bar{\tau}) + \rho \vec{g} + \vec{F} \qquad (3)$$

where p is the static pressure, $\bar{\tau}$ is the stress tensor, $\rho\vec{g}$ and $\vec{F}$ are the gravitational body force and external body force, respectively.

For two-phase flow simulations, the Euler-method was adopted. It is reported that standard k-ε turbulence model is robust, economic and accurate for a wide range of turbulent flows in industrial application [19], therefore, standard k-ε turbulence model was chosen as turbulence model. Eq. 4 and Eq.5 represents the turbulence kinetic energy (k) and its dissipation (ε), respectively, [20].

$$\frac{Dk}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\frac{v_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right)\frac{\partial k}{\partial x_j}\right] + v_t\frac{\partial u_j}{\partial x_j}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] - \varepsilon \qquad (4)$$

$$\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j}\left[\frac{v_t}{\sigma_\varepsilon}\frac{\partial k}{\partial x_j}\right] + C_1 v_t\,\frac{\varepsilon}{k}\frac{\partial u_j}{\partial x_j}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] - C_2\frac{\varepsilon^2}{k} \qquad (5)$$

The magnitudes of the coefficients seen in the above equations are given as follows:

$$C_\mu = 0.09 \quad C_1 = 1.44, C_2 = 1.92 \;, \sigma_k = 1.0 \;, \sigma_\varepsilon = 1.3$$

The separation efficiency (η) were calculated as given in Eq.6. [21].

$$\eta = 100 * \frac{\dot{m}_{oil\,inlet} - \dot{m}_{oil\,content\,in\,gas\,outlet}}{\dot{m}_{oil\,inlet}} \qquad (6)$$

For a continuity equation the (q) phase, this equation has the following form [19].

$$\left(\frac{1}{\rho_q}\right) * [\nabla \cdot (\alpha_q * \rho_q * v_q) = S_{\alpha q} + \sum_{p=1}^{n}(\dot{m}_{pq} - \dot{m}_{qp})] \quad (7)$$

3. RESULTS AND DISCUSSION

Validation of the study was successfully achieved by comparing the results with the data of Efendioglu et al., 2014 [21]. The difference between the two studies was found to be 0.5% for the distance between the inlet and diverter plate. It is seen that the gap between the results closes to 0.1% for the other distances (Fig.6).

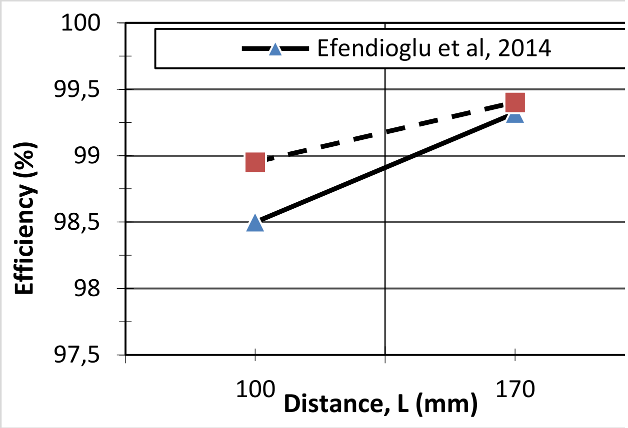


Figure 6. Comparison of the present study with the data of Efendioglu et al., 2014 [21]

Horizontal separators have been used to separate the gas and oil by means of inlet diverter(s) that isolates the oil and gas quickly by altering the direction and velocity. After that, in gas and liquid interface the liquid droplets are impacted by gravitational force in the gravity settling part. For various inlet velocities, the liquid entrainment in the gas outlet was measured. Fig.7 demonstrates the velocity vector for mixture phase when the diverter plate at L=200 mm and the mix enters the separator with 0.75 m/sec. It is seen that the mixture issuing from the top inlet with a high velocity impinges on the diverter plate by the gravitational effects. After the impingement, the velocity decreases and flow change its direction and most of the fluid is diverted downward in the separator. Furthermore, the momentum of the droplet is exchanged to some extent. Thus, because of the impact of gravity the droplets are settled down before the gas flows toward the exit with a lower velocity. This low velocity is required to give enough retention time for the oil droplets and allow the settlement of the oil film (Fig.6). This outcome agrees with the literature [20, 22].

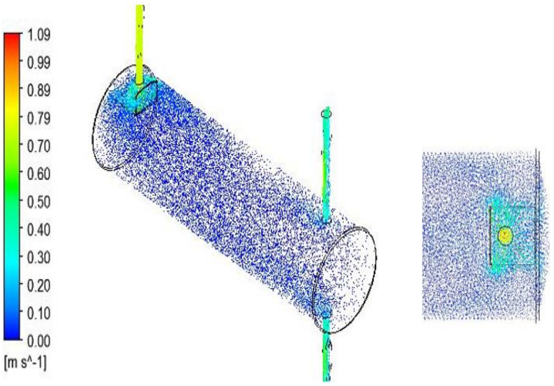
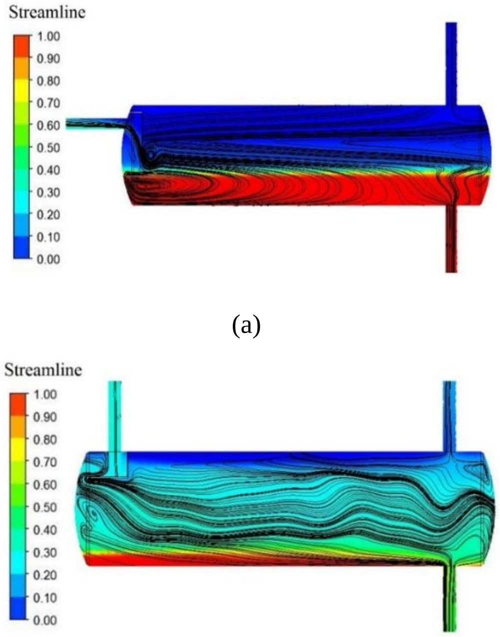


Figure 7. Velocity vector of horizontal separator top inlet when L = 200 mm and velocity 0.75 m/s

The flow field for the inlet velocity of 0,25 m/s at the distance of L=200 mm at the side inlet is demonstrated in Fig. 8. The occurrence of the streamline will impact the separation efficiency as oil droplets will exit with the gas from the gas outlet. The upsurge of vortex flow of mixture in separator leads to the declining efficiency of separation.

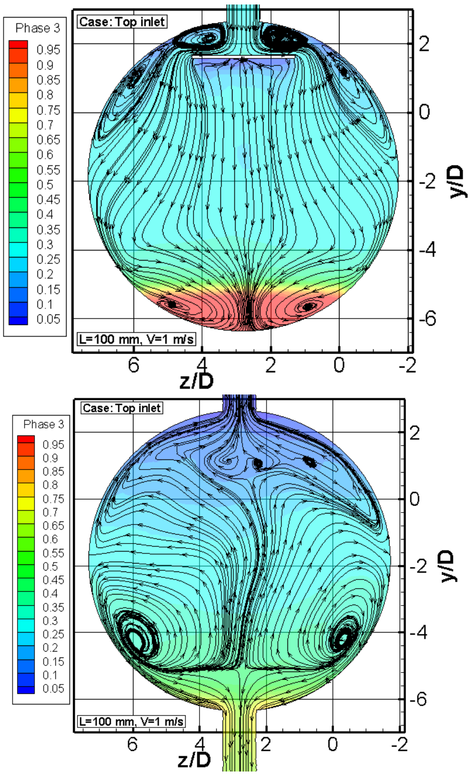
As shown in Fig.9 initially, as the mixture entered the separator the velocity was 1 m/s and distance between diverter plate from top inlet was 100 mm. The oil droplets move downward to the separator, gas attempting to move up to the top of it. Moreover, by the increase of the velocity of the mixture inlet, the streamlines will clearly show more swirl stream. The occurrence of the swirl stream will impact the separation efficiency as oil droplets will exit with the gas from the gas outlet. When upsurge the vortex flow in separator the efficiency of separation of the mixture is decreased.



(a)

(b)

Figure 8. Streamlines values for L=200 mm and velocity 1 m/s (a) side inlet (b) top inlet



(b)

Figure 9. Streamlines colored by velocity values for L=100 mm and velocity 1 m/s (a) Cut at the half of the inlet pipe, (b) Cut at the half of the outlet pipes

Volume fractions for oil and gas phases are given in Fig.10 and Fig.11 for various inlet velocities. It is seen that subsequent the collision of the mixture with the diverter plate, the layers of oil fraction change its color from red to blue that means when the velocity increases the less amount of oil separates from the mixture. The intersection between these layers indicates a fluid mixture between oil and gas phases. When velocity increases from 0,25 m/s to 1,00 m/s the region of mixture layers extends that indicates lower separation efficiency as stated in the literature [17, 21].

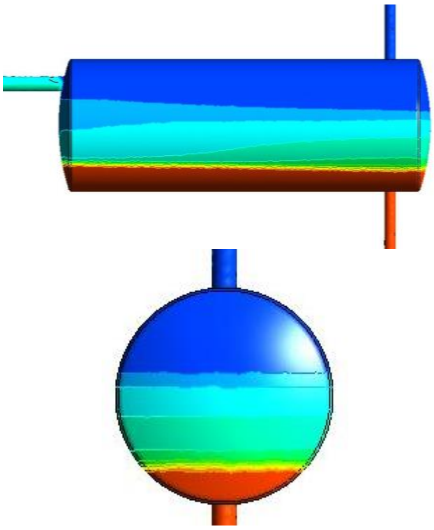


Figure 10. The volume fraction of phases for V=0,5 m/s, at diverter plate distance L=150 mm

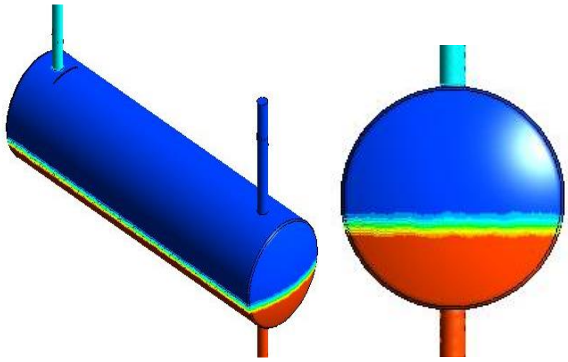


Figure 11. The volume fraction of phases for V=0,25 m/s, at diverter plate distance L=150 mm

Change of efficiency as a function of the mixture inlet velocity is provided in Fig.12, Fig.13 and Fig.14 for various distances between the inlet and the diverter. It is seen that there is an inverse correlation between the efficiency and the inlet velocity. As the inlet velocity increases the overall separation efficiency of the separator decreases gradually. The highest separation efficiency is obtained for L=200 mm as 99,772%. While the distance between the inlet and the diverter decreases the separation efficiency decreases to 99,688% for L=150mm and 99,608% for L=100 mm. It must be kept in mind that these efficiencies are obtained for the lowest inlet velocity. As indicated before, when the inlet velocity increases the separation efficiencies decreases. Regardless of the distances, the side inlet provides higher efficiency than the separation efficiency obtained for the top inlet.

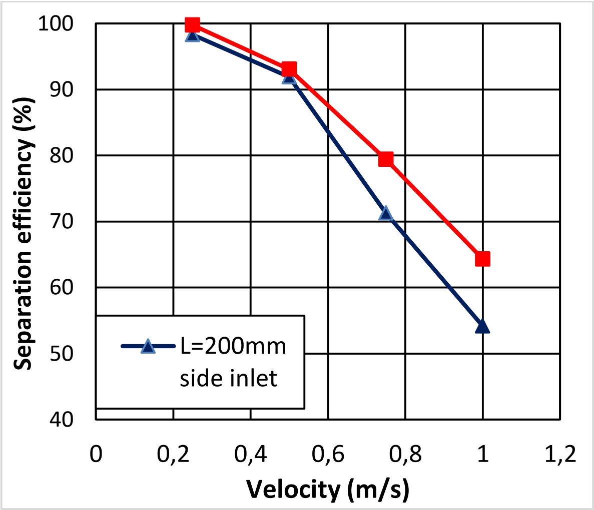


Figure 12. Change of separation efficiency with the side and top inlet velocities for L=200 mm distances between the inlet and diverter plate

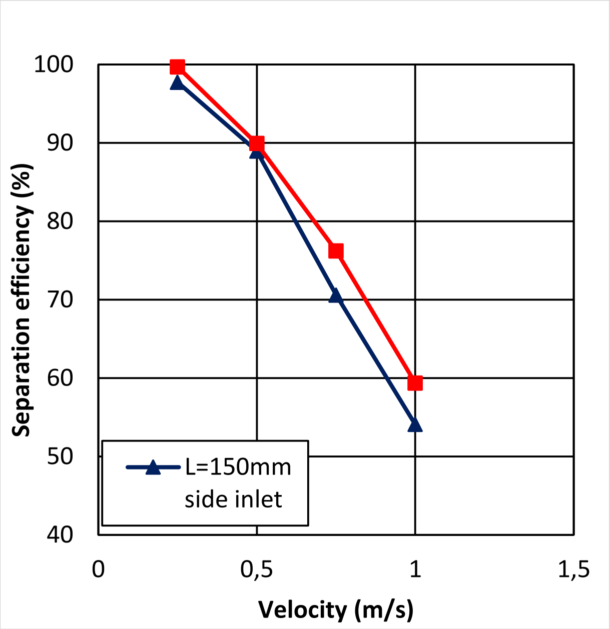


Figure 12. Change of separation efficiency with the side and top inlet velocities for L=150 mm distances between the inlet and diverter plate

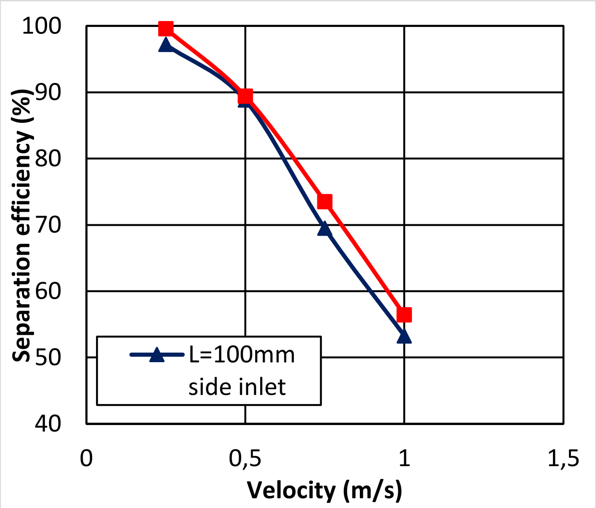


Figure 13. Change of separation efficiency with the side and top inlet velocities for L=100 mm distances between the inlet and diverter plate

4. CONCLUSIONS

The present paper reveals the effect of the mixture inlet velocity and the distance between the inlet and the diverter plate in an oil-gas separator used in the oil industry. For this purpose, various plate distances, inlet locations, and velocities were considered by means of CFD technique. The validation of the numerical results was successfully achieved by comparing with the available data obtained in the open literature. It is found that there is an inverse correlation between the inlet velocity and the separation efficiency and direct proportion between the distance and efficiency. Positioning the inlet pipe to the side of the separator provides higher separation efficiency than locating the pipe to the top of the separator. The highest distance between the inlet and the diverter provides the highest efficiency.

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