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CFD simulation of designed coalescing plates for separating water and oil in water treatment plants used in petroleum projects

Petrol projelerinde kullanılan su arıtma tesislerinde su ve petrolün ayrıştırılması için tasarlanan birleştirilmiş plakaların CFD simülasyonu

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Abstract

Petroleum production generates an immense amount of oily polluted water which may have harmful effects on environment. At the same time, produced water is the biggest waste stream produced in the petroleum industry. In the past decades produced water treatment was the point of attention. However, the processes of treatment to separating water and oil have been enhanced gradually. This study used a two-dimensional computational fluid dynamics (CFD) model to investigate the effect of space between coalescing plates, orifice diameter and mixture inlet velocity on separation efficiency. Spacing values of 8, 12, 16, 20, 24 mm between plates, orifice diameters of 10, 15, 20 mm with different cross sections (e.g., cylindrical, rectangular, ellipse, and triangle) along with four different mixture inlet velocities of 0.02, 0.03, 0.04, 0.05 m/s were utilized to discover the effect of each parameter on the separation efficiency. The investigation revealed that the increase in the distance between plates was inversely proportional to the separation efficiency and the increase in the velocity of the mixture or mass flow rate inlet was inversely proportional to the separation efficiency. It was also found that the highest separation efficiency was obtained for the cylindrical shape with a hole diameter of 15 mm. It was also observed that the separation efficiency varied between 25% and 99.25% depending on the values of mixture inlet velocities and distance between plates.

Keywords: CFD, Two-phase flow, Velocity of mixture, Volume of fluid, Laminar flow

Öz

Petrol üretimi, çevreye zararlı etkileri olabilecek bol miktarda yağ ile kirlenmiş su ortaya çıkarmaktadır. Aynı zamanda üretilen su petrol endüstrisinin ürettiği en büyük atık akımdır. Geçmiş yıllarda dikkat, üretilen su işlemleri üzerineyken suyu yağdan ayırma yöntemleri zamanla önemli şekilde iyileştirildi. Bu çalışma kapsamında birleşik plakalarda, plakalar arasındaki mesafenin, orifis çapının ve karışım giriş hızının ayırma verimine olan etkilerini incelemek için iki-boyutlu hesaplamalı akışkanlar dinamiği (HAD) modeli kullanıldı. Ayrılma verimini etkiyen parametreleri belirleyebilmek için 8, 12, 16, 20, 24 mm plakalar arası mesafesi, 10, 15, 20 mm farklı enine kesit (örneğin, silindirik, dikdörtgen, elips ve üçgen) orifis çap değerleri ile 0.02, 0.03, 0.04, 0.05 m/s olan dört farklı karışım giriş hızları kullanıldı. Bu inceleme plakalar arası mesafedeki artışın, karışım giriş hızındaki artışın veya kütle akış debisinin ayrılma verimi ile ters orantılı olduğunu ortaya çıkardı. Diğer taraftan en yüksek ayrılma verimi 15 mm delik çaplı silindir şeklindeki orifiste elde edildi. Üstelik ayrılma veriminin, plakalar arasındaki mesafeye ve karışım giriş hızlarına bağlı olarak %25'ten %99.25'e kadar değiştiği gözlemlenmiştir.

Anahtar kelimeler: HAD, İki fazlı akış, Karışımın hızı, Akışkanın hacmi, Laminer akış

1 Introduction

Underground and well fluids are often compound mixtures of gas, oil, and water. These fluids are required to be separated so that each of them can be used for a specific application. One of the easiest ways to separate oil from water is the use of utilizing tank in which gravity enforces the heavier fluid to be at the bottom of the tank. For example, water, heavier than oil, sinks to the lower part of the tank and the oil stays at the top of the tank. Therefore, oil can be either extracted for further treatment or sent back to reservoir tanks. As a result, it is necessary to remove water from the oil prior to the delivery to the pipelines [1]. The oil industry has various issues in the process of separating water from oil. For the purpose of increasing oil production, gas and oil companies continuously seek for more efficient methods to decrease the amount of water in the mixture. Since the eighteenth century, water was produced as a mixture of water and hydrocarbon. This has disappointed and challenged the industry on by what means to separate the disposable from the previous. Over the years, different methods of separation have been invented such as; installation of stock reservoir, skim pit, gun barrel, free water knock out instrument while the greatest novel one has become the water treatment plant. Once the fluids delivered to the separation tank, the oil and gas will be separated while the remained water flows through the water treatment plant for further processing [2].

The water, produced and brought to the surface with natural gas and crude oil, is typically polluted cannot be used for drinking or irrigation. The biggest waste by volume in oil production process is generally water [3]-[5]. The compound of the fluid mixture relays on how existence of crude oil or gas is generated. It usually contains either gaseous hydrocarbon or liquid, suspends or dissolved solids, settling like sand or slit, and inserted fluids and additives. Because of the high level of the toxicity and solubility in the remained water, it enlarges a major environmental risk for mankind [7]. There is testimony that hydrocarbon could give rise to cancer and other serious diseases, in accordance with the U.S. environmental protection agency [8]. That is why decreasing exposure to these materials is fundamental for preserving marine and human life [9].

In the oil manufacturing industry, generated water is the main volume waste stream. The ratio of water to oil is nearly 3:1 [10]. It subsists as a result of manufacture gas and oil from subsurface tanks [11]. The amount of water produced from the oil manufacturing process has augmented sensationally and it is not stable through an oils operation time [12]. It is proven that there is a negative correlation between water production and oil [3]. It a number of older fields, the water could surpass more than 90% [10],[12]. Globally, the amount of water production is anticipated to raise in the upcoming, this states that the influence of clearing manufactured water into the ecosystem will come to be an immense concern [12],[6]. Presently, arise number of researchers have utilized computational fluid dynamics (CFD) to examine oil water separation. It has also been utilized as basis of oil water separation experiments because defining the effect of various geometries and operation process on the efficiency of separation by doing and carrying out experimentation can be quite complex and costly [13]-[16]. CFD computation has proven to be more applicable and advantageous with regards to the experiments. Therefore, CFD program is utilized in this study [17],[18].

2 Methods

CFD is a numerical technique facilitating the investigation with the help of fluid dynamics. Utilizing CFD program assists in building computational model which represents a device or system to be examined. In this program, physical and chemical properties of the fluid are typically applied and the program solves the governing equations to provide output parameters for the fluid dynamics and associated physical phenomena. Thus, CFD program can be seen as a complicated computational-based designing and analysis procedure [19].

Volume of fluid (VOF) model is, on the other hand, a superficial-tracing technique utilized to an immovable Eulerian mesh. It is applied for calculating additional unmixable fluids where the location of the boundary among the fluids is of interest. In this model, a set of momentum equation is shared by the fluids, and the volume of the fraction of every fluid in all computation cells is affected throughout the domain. The utilization of the VOF formulation comprise stratified streams, filling, sloshing, free-superficial streams, the movement of liquid after a dam breakdown and the movement of great bubbles in a liquid boundary [20].

The water was selected as primary phase since the water volume fraction was higher than in oil-water mixture. Here, the oil was termed as a secondary phase. The ratio of water to oil was 3:1 while no-slip was set for both phases. Figure 1 shows the diagram for coalescing plate and entrance of mixture along with the water and oil exit can be seen. Computational domain illustrated in Figure 2 has mass flow rate inlet boundary at the left side while pressure outlet boundary condition was imposed at the exit of the boundary and two-cell zones were used. The mass flow inlet was utilized because it was the simplest condition for the inlet boundary. Surface tension effect had to be active in two layers of water and oil, the surface tension coefficient was taken as zero in gravity separation for laminar mode flow.

Figure 3 shows the enlarged view of the plate positions and the dimensions of the distance between plates along with the length of the plate. The width of the computational domain was set to 537 mm while the distance between the plates were chosen to be 8, 12, 16, 20 and 24 mm.

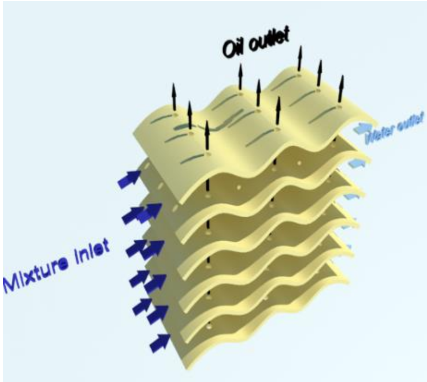

Figure 1: Coalescing plate diagram water and oil direction flow.

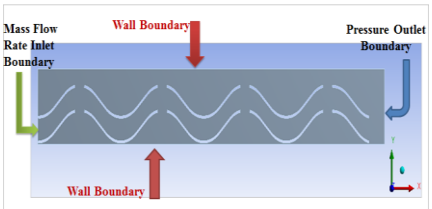

Figure 2: Front view of coalescing plate diagram with boundary conditions.

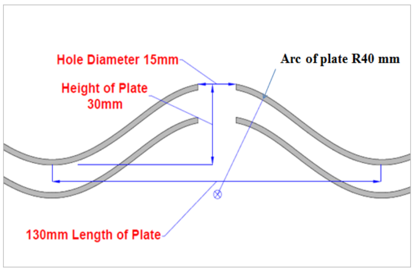

Figure 3: Boundary plate dimensions.

Quadrilateral elements shown in Figure 4 were placed into the computational domain ranging from 29000 elements to 39000 elements for the distance between the plates of 8 mm and 24 mm, respectively. Optimal mesh size was determined based on the average velocity and the characteristics of the fluid velocity between the plates. Specifically, minimum mesh sizes were set to 0.00014 m near the walls to capture velocity gradients while maximum mesh sizes stayed at 0.001 m in other part of the domain. The quality of the mesh was also monitored based on the skewness of the elements. Most of the elements' skewness were below 0.25 due to the square shape of the computational domain. However, few elements around the corner of plates showed maximum skewness of 0.45 considered to be in good cell quality.

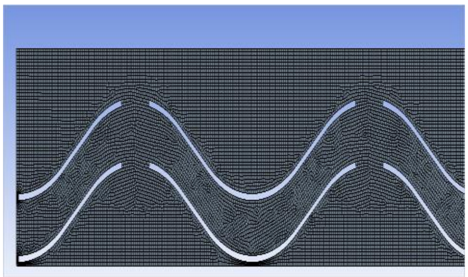

Figure 4: Mesh elements in the computational domain.

In the present study, Reynolds number for the flow simulation was defined as $\mathrm{Re} = \rho V d_h/\mu$ was density of fluid, V was the velocity of fluid, d_h was equivalent diameter of the flow channel. Reynolds number of the studied cases in the present study stayed in the laminar flow regime; therefore, governing equations for laminar flows were implemented for the solver.

Volume of fraction equation is the following of the user boundary among the phases and skilled by the resolution of a permanency equation. For the phases, this equation has the pursuing arrangement [20],[21].

$$\frac{1}{\rho q}\left[\nabla\cdot(\alpha q*\rho q*vq) = S\alpha q + \sum_{p=1}^{n=1}(m\,pq - m\,qp)\right] \qquad (1)$$

Surface tension continuum force equation is given as [25].

$$\gamma = \frac{F}{L} \qquad (2)$$

Momentum equation can be given as,

$$\nabla\cdot(\rho v v) = -\nabla p + \nabla\cdot[\mu(\nabla v + \nabla V t)] + \rho g + F \qquad (3)$$

Mass flow rate equation can be expressed as Mass flow from each phase;

$$\rho\, phase * area\, phase * V \qquad (4)$$

Equation (4) states the continuity equation or conversation of mass, common method of the mass improvement equating and validated for incompressible fluids in addition to compressible streams. The basis (Sm) is the mass additional to the main part of fluid from or bulk phase the droplet part of fluid or globule phase shown below [20],[21].

$$\nabla(\rho \mathrm{V}) = \mathrm{Sm} \qquad (5)$$

The separation performance of an oil-water separator system was assessed as stated by less volume of water separated. In other side, the high stability of mixture designates the minimum percentage of water separation from oil in water mixture [22],[23].

Oil removal separation efficiency

$$(\%) = (\mathrm{CI}-\mathrm{CO})/\,\mathrm{C} \qquad (6)$$

Here, CI stands for water inlet oil content while CO represents for water outlet oil content.

Numerical results in the present study were validated with Ivanenko et al. [27]. The validation of the results was performed based on the average velocities between the plates when the distance between the plates were the same for both Ivanenko et al. [27] and the present study. Both average velocity between the plates and the characteristics of the fluid flow were in good agreement with Ivanenko et al. [27].

3 Results and discussion

The use of coalescing plates in the removal of oil from water is a commonly used method in industry. However, determination of separation efficiency can be difficult to measure depending on the varied parameters. In the present study, a two-dimensional computational fluid dynamics model was prepared to simulate removal process of oil from water in coalescing plates system.

Figure 5 indicates that when the flow inlet velocity is 0.0500 m/sec and the distance between plates is 20 mm, the flow is laminar and the stream line velocity arises in a curvilinear channel to 0.16511m/sec. The region of the whirl flow can be observed in the curvilinear channel and at the orifice diameter of the plate as discussed by Ivanenko et al. [27].

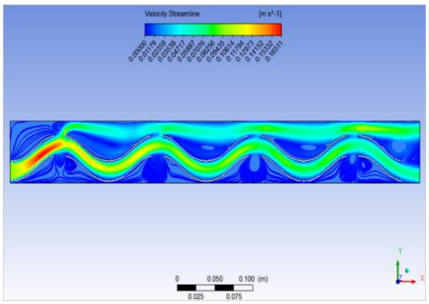

Figure 5: Velocity Stream lines when h = 20 and inlet velocity = 0.05 m/sec.

Figure 6 shows that when the velocity of the mixture inlet is 0.0300 m/sec and the distance between plates becomes 12 mm, the velocity magnitude rises to 0.10061 m/sec. This variation in the velocity leads to the occurrence of the separation in the coalescing plate. It is important that the velocity magnitude must be higher than the velocity of mixture flow inlet [27].

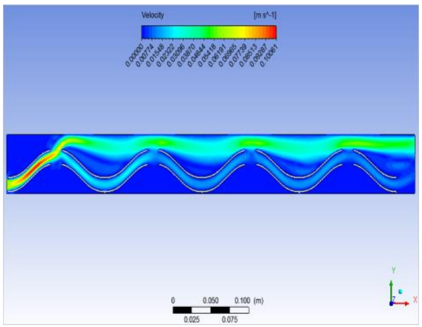

Figure 6: Magnitude of velocity when h = 12 and velocity = 0.03 m/sec.

Figure 7 expresses the rise of velocity vector 0.16511 m/secwhen using the distance between plates to be 20 mm compared to the velocity of the mixture inlet to 0.0500 m/sec. This is mostly caused by the impairment of velocity vector in the coalescing plate. It is noticed that the velocity vector is higher than the velocity of mixture flow inlet which is very essential for separation process for all the studied cases [27].

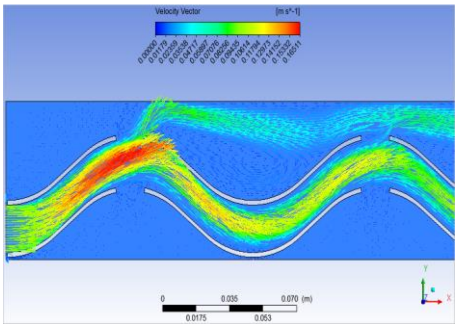

Figure 7: Velocity vector when h = 20 and velocity 0.05 m/sec.

The surpass of oil particle leads to an increase rate larger than the velocity laminar flow surrounding them. The velocity difference leads to addition particle collisions of smaller and bigger globules. The globules become larger and speed up their upward movement as a result they trapped by coalescing plates or corrugated plates on the top section of the plate. The velocity will be higher compared to the velocity of the mixture in the gap. All of the figures given below show that when the distance between plates were 8, 12, 16, 20, 24 mm, both x and y-velocities increased.

Figure 8 displays that using the velocity of mixture inlet 0.0300m/sec and the distance between plates 12 mm results in the rise of the x-velocity to 0.08406m/sec, the most fundamental part is that the x-velocity is higher than the velocity of mixture flow inlet.

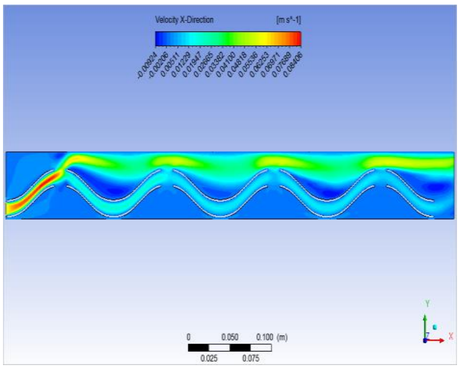

Figure 8: Velocity in x-direction when h = 12 and velocity = 0.03m/sec.

Figure 9 expresses that applying the velocity of mixture inlet as 0.0300 m/sec and the distance between plates to be 12 mm increased the y-velocity to 0.06372 m/sec. The high vertical velocity (y-axis) assists the separation of bulk phase and globule phase [24],[25],[27].

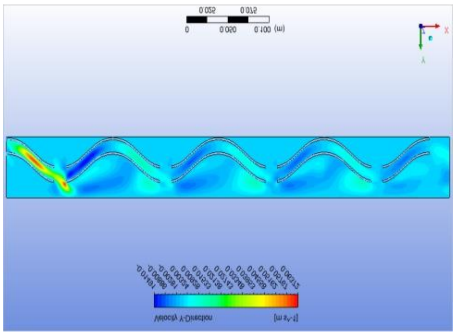

Figure 9: Velocity in y-direction when h = 12 and velocity = 0.03m/sec.

The volume of fraction is the key for indicating separation efficiency; this research observed a fluid entry with percentage of water 71.38% and oil is 28.62% in the outline. This result agrees with studies in this field which is the amount of 1:3 oil in water. The water and oil layers are separated clearly with an interface and a mixed section between the water and oil is attained by volume of fluid VOF simulation model [28]. When the layer of water separated obviously indicate high efficiency. However when water layers law or not obviously seen in the outline indicate law efficiency. When the distances between plates are increased the separation efficiency and the water volume fraction are decreased in the outlet.

Figure 10 indicates that when the oil volume of fraction is 0.28616% velocity of mixture inlet 0.04m/sec and applying the distance between plates 16 mm, the separation efficiency is 80.00%. When the layer of oil invisible in the water outline indicates high separation efficiency. Conversely, when the oil layers obviously displays in the water outline indicate law separation efficiency.

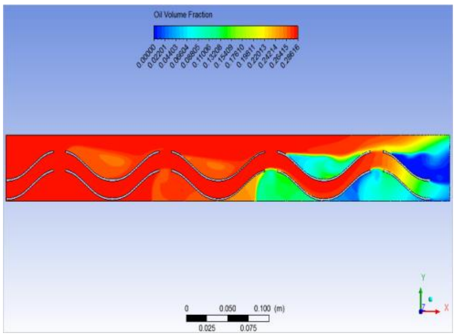

Figure 10: Oil volume of fraction when h = 16 mm and velocity = 0.04 m/sec.

The mixture stability assessed in accordance to the minimum quantity of separated water. In another way, the minimum percentage of separated water denotes the high stability of the mixture. This study found that the separation efficiency shown in Figure 11 varied between 24% and 99% for different plate spacing values ranged 8, 12, 16, 20, 24 mm and mixture inlet velocities from 0.02 m/s to 0.05 m/s. As the distance between plates increased, oil removal efficiency decreased. Also, when velocity of the mixture or mass flow rate of the mixture increased oil removal separation efficiency decreased. The increase of velocity of mixture inlet leads to the increase in the mass flow rate of the mixture inlet 0.732, 1.0974, 1.46, 1.82, 2.914 kg/sec, which cause the decrease in the separation efficiency. This is confirmed by other studies [26],[27],[29].

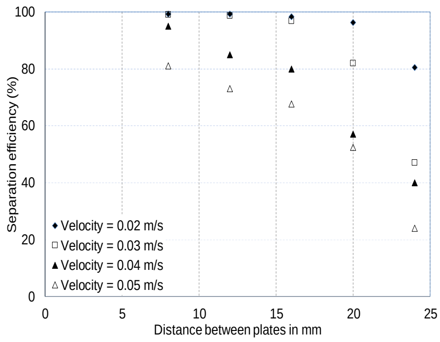

Figure 11: Separation efficiency and distance between plates, when velocity 0.02,0.03,0.04,0.05 m/sec.

4 Conclusions

In the current study, a research is carried out to have an understanding on the oil-water two phase flow phenomenon in coalescing or corrugating plate and its separation. The research supply's an outline with using ANSYS FLUENT commercially presented CFD simulation software so as to yield the benefit of using a CFD and selected VOF oil-water phase's model.

In general oil industry consists of the process of exploration, extraction and marketing. Various types of procedures are available for separating this compound mixture. The most important compositions are oil, gas and water, these substances are required to be separated before the transmission and marketing. The quality of water has been estimated for a number of fluid systems in both water and oil continuous regime if the water is primary phase and oil is secondary phase, by coalescing plate separator water and oil can be separated.

Produced water treatment can be classified in several major processes every class could be divided in to some subclasses. The most widely utilized process of produced water treatment is coalescing or corrugated plate. Coalescing plate applied in this process in order to accelerate the separation process. The election of an operation for handling is so much relying on the characteristic of the produced water and its source. It also depends on the eventual purpose of its utilization. In this research parameters such as velocity, orifice diameter, distance between plates, and volume of fraction and separation efficiency have been observed. It is found that the separation efficiency has negative correlation with velocity. Additionally, the smaller the spacing between plates is, the better the separation efficiency. In this research several hole diameter have been observed 10, 15, 20 mm with different shape such as (cylindrical, rectangular, ellipse, and triangle). It is found that the best separation efficiency was by applying coalescing plates which has cylindrical shape with a hole diameter of 15 mm diameter.

5 Nomenclature

Symbol Description

A	:	Area	(m^2),
M	:	Mass	(kg),
m	:	Mass flow rate	(kg/s),
F	:	Force	(N),
Q	:	Volumetric flow rate	(m^3/s),
Re	:	Reynolds number	
u	:	Local velocity	(m/s),
V	:	Velocities	(m/s),
W	:	Mass flow Density rate	(kg/s),
ρ	:	Density	(kg/m^3),
μ	:	Viscosity	(kg/ms),
γ	:	Surface tension	(N/m),
α	:	Volume of fraction	(%),
∇	:	Delta or nabla	
∂	:	Partial	
L	:	length	m,
h	:	distance between plates	mm,
D	:	hole diameter	mm,
p	:	phase one	
q	:	phase two	
Hi	:	height of the plate	mm,
Le	:	length of the plate	mm,
Hd	:	plate hole diameter	mm.

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