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Research Article

Effects of Corrugated Plates on Separation Performance

Mehmet ORUÇ, Sedat YAYLA*

Van Yüzüncü Yil University, Engineering Faculty, Mechanical Engineering Department, 65080, Van, Turkey

Mehmet ORUÇ, ORCID No: 0000-0001-7497-7613, Sedat YAYLA, ORCID No: 0000-0001-6640-6511

*Corresponding author e-mail: syayla@yyu.edu.tr

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Abstract: There are water, gas and some solid materials in mixtures extracted from underground. The method commonly used for separating the extracted mixtures of crude oil from water is the use of corrugated plates. The plates are used for gravity separation usually. In this study, the effects of three Re numbers of mixtures (3500, 4800, 6100), three values for the ratio of diameter of the hole to the width of the plate (d/w) (0.017, 0.025, 0.033) and three mounting angles of the plates to the separation unit (10, 30, 50 degrees) on the separation performance were investigated. With less experimentation and no impact on separation performance, the optimization process was carried out utilizing the design of Box-Behnken and the Response Surface Method (RSM). In addition, the same system was designed in the Computational Fluid Dynamics (CFD) program, and the optimum experiment was carried out numerically. The experimental and numerical results were compatible with one another. The ultimate separation performance was achieved as 99.25% when the mounting angle was 27 degrees, the d/w was 0.029 and the Re number was 4850.

Birleştirilmiş Plakaların Ayrıştırma Verimliliği Üzerine Etkileri

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Anahtar Kelimeler
Box-Behnken tasarımı,
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Öz: Yeraltından çıkarılan karşımın içinde su, gaz ve bazı katı maddeler mevcuttur. Ham petrol olarak çıkartılan karışımın sudan ayrıştırılmasında en yaygın olarak kullanılan yöntem, yerçekimsel ayrışma metotlarından biri olan oluklu levhaların kullanıldığı ayrışma yöntemidir. Bu çalışma kapsamında, ele alınan petrol-su karışım numunesinin 3 farklı Re sayısı (3500, 4800, 6100), oluklu levhaların 3 farklı delik çapının levha genişliğine oranı (0.017, 0.025, 0.033) ve oluklu levhaların ayrışma sistemine 3 farklı montaj (10, 30, 50 derece) açısı parametrelerinin ayrışma verimliliğine etkisi incelenmiştir. Yapılması gereken deney sayısını azaltmak ve böylece maliyet ve deney süresinden tasarruf sağlamak amacıyla, ayırma veriminin en yüksek değerini bulma olasılığını etkilemeden, Box-Behnken tasarımı ile Yanıt Yüzey Yöntemi (RSM) kullanılıp optimizasyon işlemi gerçekleştirilmiştir. Ayrıca Hesaplamalı Akışkanlar Dinamiği (CFD) programında aynı sistem tasarlanarak optimum deney, sayısal olarak gerçekleştirilmiş ve deneysel ve sayısal sonuçların birbiriyle uyumlu olduğu görülmüştür. En yüksek ayırma verimi %99.25 olarak montaj açısı 27 derece, d/w 0.029 ve Re sayısı 4850 olduğunda elde edilmiştir.

1. Introduction

With the development of technology and the increase in the quality of life, the demand for energy is increasing day by day (Sahin et al., 2021). Virgin oil is the most widely used energy source among fossil fuels. Virgin oil has been extracted for 1900 years and is put out as a mixture of virgin oil, gas, and groundwater. Depending on the advances in technology, more modern separation facilities were established in order to separate the mixtures extracted from underground (Güreşçi et al., 2017; Yayla et al., 2019). Firstly, the mixture is moved from storage tanks to separate oil, gas, and water by passing through a separating plant including all processes to separate wastewater (Escobar, 2005). The water extracted to the surface is not clear because the wastewater includes gas and virgin oil; therefore, it can't be used for beneficial operations. There are many studies investigating the effect of the use of water generated during the extraction of fossil fuels on nature and environment. The factors affecting the ecological life cycle in fossil fuel production facilities were determined and evaluated (Yayla et al., 2017). The produced water is used in agricultural and industrial fields owing to these methods, priority technological methods were determined, and the results of all these processes were brought together with a continuous decision method (Teksin & Yayla, 2017).

The most effective waste in the oil generation process is usually wastewater (Hashim et al., 2009; Razi et al., 2009 and 2010). This waste mixture contains either gaseous hydrocarbons or settled sand or clay materials (Veil et al., 2004). It poses a serious environmental problem for humanity due to the high amount and solubility of toxins in the wastewater (Zhaohui et al., 2003). As a result of the analyses carried out by the U.S.A. Environmental Protection Agency, it was stated that hydrocarbons increase the risk of cancer and other serious diseases (Agency U.S.E.P., 1998). This is why minimizing exposure to these materials is of paramount importance to protect human and aquatic life (Reusser & Field, 2002). The water produced by the oil production sector comprises the majority of the waste, and the oil-water ratio is approximately 3:1 (Halliburton, 2010). Wastewater comes from the production gas and oil (James & Rainer, 1993). It is estimated that the wastewater comprises about 200 million barrels per day globally (Khatib & Verbeek, 2002). During fossil fuel extracting the surface, the water come out of the ground together with the oil rises at a substantial rate and this rise in the production of water never remains constant throughout the oil production. Also, that situation assists inverse relationship between oil and water extraction (Razi et al., 2009). In fields where oil and water have been produced for many times, rate of water may nearby 90% (Khatib & Verbeek, 2002; Halliburton, 2010). The amount of wastewater generated during the production of fossil fuels is increasing day by day and this wastewater poses a serious threat to the environment since it cannot be used in any process (Halliburton, 2010). Many methods have been developed to separate oil-water mixtures from each other (Yayla et al., 2017). The gravitational separation method was also evaluated over many years. This method, supported by varied many studies, identifies techniques that are suitable for separating, which include materials of separation with dissimilar intensities which occur as a result of gravity. Gravity techniques are used in extensive applications to separate wastewater in the oil production industry. The gravitational method is an advantageous, economical, and convenient technique in this sector (Ruiz & Padilla, 1996; Kenawy et al., 1997; Rao & Patil, 1998; Gu, 2001).

The mixture (oil-water-gas-sludge-solid particles) extracted from underground is first sent at high speeds to storage tanks where plates are placed vertically (Yayla et al., 2017). The mixture crashing into the plates separates some of the gas, solid particles, and water it contains, and this process is called the 1st Process. Since the separated water still contains 5-15% oil, it must be separated again. The separation of wastewater (water containing 5-15% oil) is called the 2nd Process. The basic rule of the oil/water separation unit is the application of the technique of washing. When a large volume of mixture enters the system, the oil phase aggregates at the top and the water phase collects at the bottom (Oruç & Yayla, 2022). After this event, gravitational separation occurs in the region where the oil phase agglomerates, and flotation separation occurs in the region where the water phase is located. Since the water ratio in the mixture is higher, the separation method used for these mixtures is the flotation method, which is a method included in the gravitational separation classification (Liu, 2009).

Recently, new units were developed for separation using "wavy" corrugated sheets and insoluble mixtures (Fleischer, 1984; Ostrowski, 2003). Wastewater flows along the geometry on the plates by following an undulating path according to the shape of the plate slit, and at the end of the process, it flows upwards and pours down. The oil droplets which have lower density than water move upwards and adhere to the bottom of the joined plates. When the huge number of oil droplets retained due to the adhesion force come together, they coalesce into a large droplet and gain the form of a film on the surface of the storage tank. The fluid mixture crosses the upper part of the film plate with the kinetic effect of low height and moves towards the top area of the channel and collects on the surface of the mixture. So, this event allows the combined droplets in the system to reach the fluid surface. This design determines the conditions for the efficiency of oil droplets reaching the surface (Ivanenko et al., 2010).

Nowadays, an increasing number of researchers use the computational fluid dynamics program (CFD) to research the separation of wastewater. At the same time, although the process of performing the experiments is complex and costly, it is used as a basis for oil-water separation experiments because it is useful in determining the effect of various geometric shapes and the process on separation (Wang & James, 1998; Andresen et al., 2000; Klasson et al., 2005; Zhao et al., 2005). Computational fluid dynamics data has proven to be more applicable and consistent with experiments in recent years (Cooper & Coronellat, 2005; Zhong et al., 2006). The corrugated plate separator as one of the main elements in the gravity separation system was supported by previous studies and designed apparatus (Guerin, 2002). This apparatus is used to separate oil and water with different densities in the form of a standard separation method. The separation unit must be in harmony with three upwards plates, or interlocking symmetrical plates, normally 10-20 mm wide. The principle of plate system separation is to allow the oil droplets to rise and coalesce, to gain larger volume, and to allow these large volumes of oil droplets to be separated more easily (Oruç & Yayla, 2020). The separation performance of the corrugated plate system can be further improved with a suitable design. A separator designed with a symmetrical corrugated plate system is similar to the gravity separator technique used in the past. The performance of this system can be increased by placing parallel plates inside the system without the need to increase the volume of the separator.

In this study, the Re number of the virgin oil sample which supplied from Batman Batı Raman region (3 different values), the ratio of diameter of the hole to width of the corrugated plate (3 different values), and the angle of the mounting to separation unit for corrugated plates (3 different values) were investigated. Experimentally and numerically, the impact of all parameters on the separation performance was analyzed. In line with all parameters, the necessary experimental setups were established, and essential studies were analyzed. There are a lot of experiments that need to be done due to examining three parameters and three evaluation levels for all parameters. The Box-Behnken design was used within the scope of the Response Surface Method (RSM) in order to reduce the number of experiments that need to be done, to save costs and experiment time, and also not to affect the possibility of indicating the ultimate valuation of separation performance. All experiments were analyzed in terms of the experimental plan designs. The optimum experimental design (where the maximum separation performance is achieved) was designed in the Computational Fluid Dynamics (CFD) program and the same experiments were carried out numerically, and the compatibility of the experimental and numerical results with one another was examined.

2. Material and Methods

Separation is based on the principle of separation of mixtures consisting of insoluble fluids. Several parameters affecting the separation efficiency were investigated experimentally in this study. The separation performance was investigated numerically, and experimentally. Features of oily water used in the relevant calculations were measured and determined.

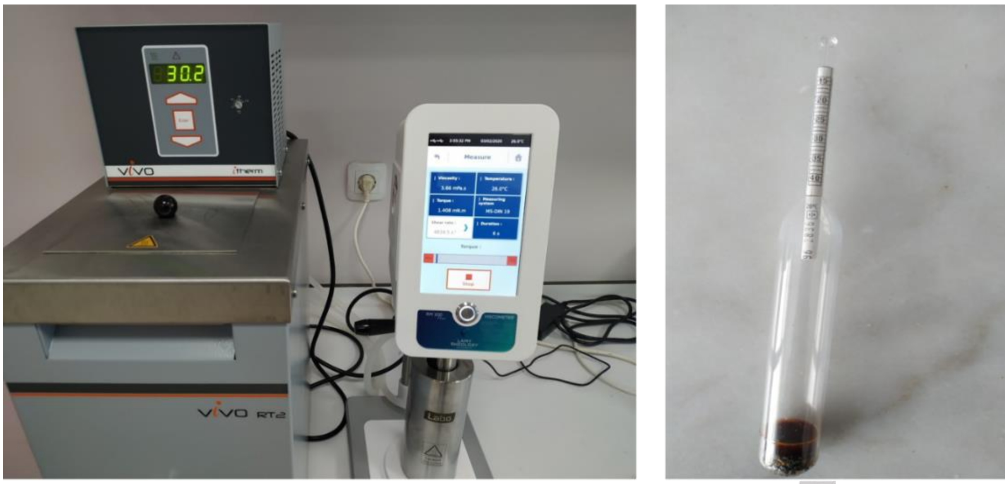
2.1. Experimental studies

Essential rheological features of the 1st Process oily water sample obtained from Batman Batı Raman oil facility are shown in Table 1.

Table 1. Features of oily water

Sample Name	Oil Ratio in Mixture (%)	Density (kg/m^3)	Viscosity (Pa. s)
Batman Batı Raman	11	820	6×10^{-3}

The viscosity of the oily water was evaluated with temperature-controlled LAMY RM 100 viscometers, and the density of the mixture was evaluated using a hydrometer, as seen in Figure 1. Firstly, the oily water used in the article was supplied and rheological features were measured, then the recommended experiments were done. Density and viscosity values of the oily water before entering the separation unit, and the separated water discharged from the separation system were measured, and the changes in the density and viscosity of the mixture were also examined.



1a 1b

Figure 1. Viscometer (1a), density meter (1b)

Figure 2 shows the separation unit used to carry out the relevant experiments. As seen in the figure, the mixture enters the separation unit using a pump. The flow rate of the mixture was adjusted by using the automation unit connected to the system. A HP10 Metallic Body Diaphragm Pump was used in the system and flow control used the automation unit. In the separation process, which was carried out by making use of the density difference between oil and water and using corrugated plates, oil collects on the surface. The oil collected on the surface of the tank is drained from the system by using the oil drain valve and accumulated in the storage tank. The water which is separated is drained to the separating storage tank with the water drain valve.

Figure 2. Experimental set-up used.

A separation unit feed storage tank with capacity 2000 liters was used in the experimental setup. It is accomplished polyethylene to be durable to shocks and high value of temperatures. In the experimental process, firstly, after the storage of the oil-water mixture, it was mixed for about half an hour. The temperature of the mixture reached the temperature used in experiments. Owing to this mixing event, homogeneity of the mixture was ensured, and the mixture was ready to be pumped into the separation unit. A diaphragm pump was used to pump the mixture into the separation system at the specified flow rate, and the flow rate was adjusted digitally through the automation unit. Due to the automation unit, the temperature of the mixture was constant at 20 ºC. The reason why all the experiments were carried out at 20 °C is that studies within the scope of the 2nd Process in the field are carried out at temperatures varying between 19-30 °C. The temperature value was kept constant at 20 °C in all experimental and numerical studies to ensure that the conducted studies were compatible with the real data in the field. Since the related study was carried out in a pilot scale treatment plant, it was desired to study the actual temperature values in the treatment plants. Studies in the relevant sector are generally carried out at 20 °C. Thus, the mixture does not need to be heated or cooled. In this way, extra energy consumption is prevented.

The separation tank used in the separation unit is metal, painted and coated to protect the metal from oxidation. There are drain devices for the discharge of the settled solid particles at the ground of tank separation is made. Virgin oil that separates and collects on the surface of the tank is discharged with a valve mounted on the upper part of the tank. The separated water and virgin oil were discharged to the wastewater and oil which separated storage reservoirs using the respective ventils. The separated water tank volume is 2000 liters while the volume of the separated oil tank is 500 liters. In Table 2, the features of corrugated plates used in experiments are given. Separation using the plate's specified features was ensured and the recommended experiments were investigated.

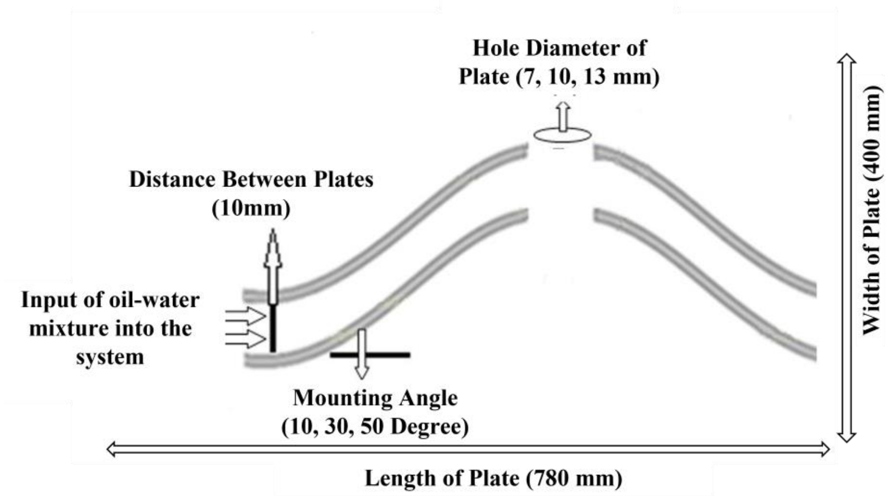


Figure 3. Features of corrugated plates.

At the same time, the features of the corrugated plates used in separated unit are shown in figure 3. All of the parameters considered in the treatment system and which values of which parameters are taken are shown in the figure.

Table 2. Characteristics of corrugated plates.

Features	Value
Length of Corrugated Plate (mm)	780
Width of Corrugated Plate (mm)	400
Distance Between Corrugated Plates (mm)	10
Diameter of Holes on Corrugated Plates (mm)	7, 10, 13

In Figure 2, the corrugated plates used for the separation of the oil-water mixture can be seen in the separation unit. When oil droplets in the mixture passing along the surface of the corrugated plates adhere to one another during flow and collect on the separation tank similar to a film layer. Since the water leaving the system has lower density than the oil, it settles in the lower part of the separation tank.

Table 3. Calculation of Re Number

Density (kg/m^3)	Velocity (m/s)	Diameter (m)	Viscosity (Pa.s)	Re Number
820	1.008	0.0254	$6x10^{-3}$	3500
820	1.382	0.0254	$6x10^{-3}$	4800
820	1.757	0.0254	$6x10^{-3}$	6100

Re number calculations, which is considered as an important parameter in the study, were calculated in line with the information given in Table 3. The diameter of all pipes in the treatment system is fixed and is 1 finger. The Re number, which is a dimensionless number, was calculated by considering the density, viscosity and pumping speed of the mixture used. The reason for wanting to work with dimensionless numbers in general in the study is to obtain generally valid results.

2.2. Optimization studies

The parameters considered within the scope of the separation system were optimized for the purpose of analyze the effect of levels of the parameters on the separation efficiency and to minimize the number of experiments. The Box-Behnken design within the scope of the Response Surface Method (RSM) was used for the optimization processes. Table 4 shows the optimized values and levels of the parameters investigated within the Trial Version of Design Expert 7 program. The values of all parameters are characterized as highest (+1), center (0), and lowest (-1). In Table 4, the experimental plan is shown, and all experiments were carried out carefully. In addition, the recommended optimum experimental design was performed both experimentally and numerically. As a consequence of optimization, 17 experiments were recommended and performed. All experiments have been recommended with the design of Box-Behnken. Also, all suggested experiments were performed twice to prove their correctness, and their average was taken as the true performance value. Variance analysis (ANOVA) in the program has been utilized to investigate the statistical importance of the variance of parameters and interaction impact between the responses and actual answer parameters. Quadratic model was examined purpose of defining accuracy of coefficient of definition (R^2).

Table 4. Levels and values of all parameters used

Free parameters	Levels		
	-1	*0*	*+1*
A- Re Number	3500	4800	6100
B-d/w)	0.017	0.025	0.033
C-Mounting Angle of Corrugated Plates to Separation Unit (α)	10	30	50

Parameters were defined in the Box-Behnken Design and their levels were specified in the relevant design. The experimental plan proposed by the optimization as a result of the identification processes is shown in Table 5. To ensure reliability of the experimental results, all the experiments that needed to be done were performed with great care in duplicate.

Table 5. Plan for experiments

Number of Experiments	d/w	α	Re Number
1	0.017	10	4800
2	0.033	10	4800
3	0.017	50	4800
4	0.033	50	4800
5	0.017	30.00	3500
6	0.033	30.00	3500
7	0.017	30.00	6100
8	0.033	30.00	6100
9	0.025	10	3500
10	0.025	50	3500
11	0.025	10	6100
12	0.025	50	6100
13	0.025	30.00	4800
14	0.025	30.00	4800
15	0.025	30.00	4800
16	0.025	30.00	4800
17	0.025	30.00	4800

2.3. Numerical studies

CFD is a subject in fluid mechanics to examine the fluid behavior by simulating the flow region and the basic differential equations of the flow; in short, it can simulate the fluid by providing numerical solution opportunities based on physical and chemical properties and is used in many application areas in many engineering branches.

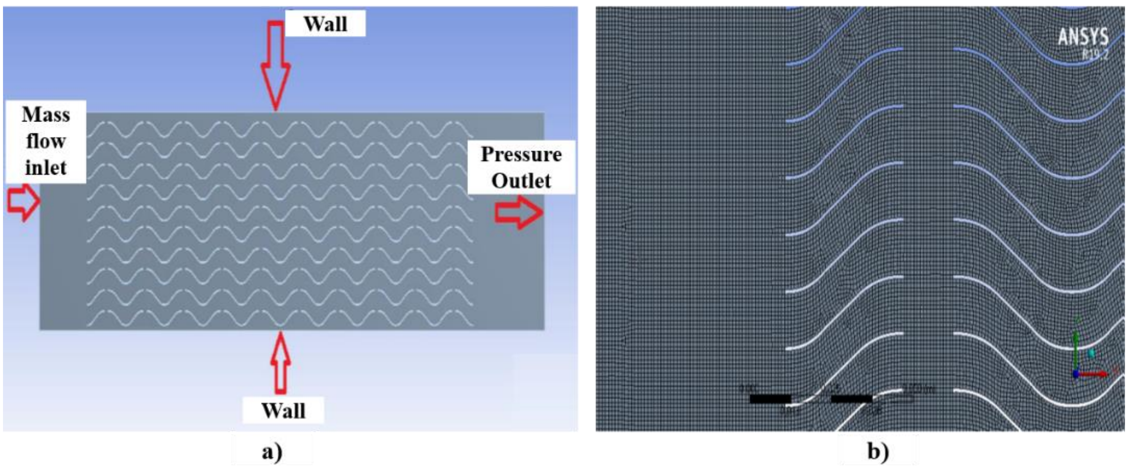


Figure 4. a) Boundary conditions applied in CFD program b) Mesh properties.

The mesh properties and boundary conditions applied for the studies evaluated within the scope of the numerical method are indicated in Figure 4. In addition, the aim was to obtain healthier results by considering the boundary conditions. Dense mesh does not mean that better solution values can be achieved, and it is necessary to determine the optimum mesh quality or number according to the kind of problem, geometry, fluid type, and properties. Since the geometry to which the problem will be applied is rectangular, the mesh geometry was selected as this geometry and the mesh with the element number 80615 was set. At the same time, the change in the applied mesh properties and the applied boundary layer conditions based on the wall (Wall) is shown. Element number is considered as 86198 in CFD program. The velocity of entry of the mixture into the system was determined as 1.008, 1.382 and 1.757, respectively. In the simulation, the focus was on the pressure outlet (dynamic pressure) since different flow velocities were examined apart from the geometrical features. The k-epsilon model was chosen because the flow regime is transitional from laminar to turbulent and turbulent. It was accepted that the flow was steady flow and the related operations were carried out.

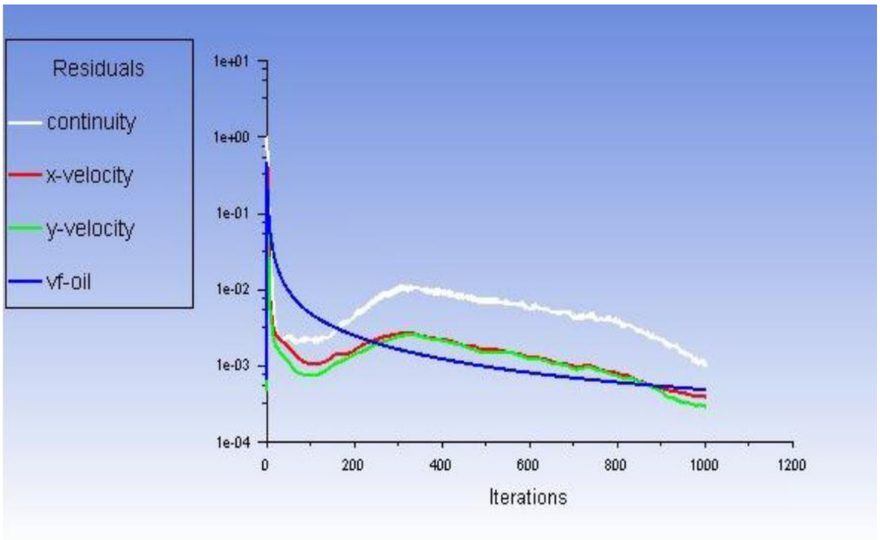


Figure 5. Iteration applied in CFD program.

In Figure 5, the iterations applied for the analysis of solutions within the scope of the CFD program to be healthier and after a certain point the parameter values considered do not change as the iteration is performed. The point to be considered while performing iteration is that the variables (x, y, z, velocity value, etc.) considered for the solution should not change by increasing the number of iterations. Considering the number of iterations and changes applied in this study, there was no change in the parameters after 1000 iterations.

Table 6. Mesh independent

Mesh Structure	Number of elements	Separation Performance (%)
Coarser	45489	97.8
Coarse	60523	98.2
Normal	70821	98.9
Fine	80615	99.25
Finer	86198	99.25

Table 6 shows the mesh independent state of the study. As can be seen from the table, when the count of elements was 86198, the maximum separation performance of 99.25% was achieved. In all numerical studies, the count of elements was taken as 86198. The transition from laminar flow to turbulent flow depends on the geometry of the model. In the fluid model, the flow regime may change according to the ratio of the total inertia forces to the total viscous forces.

3. Results and Discussion

In the planned and installed separation unit of oil-water, separation performance was investigated by using 3 different parameters (α, Re Number, d/w). Depending on all parameters considered and the levels of the relevant parameters, 17 experiments were recommended according to the optimization process. Considering the recommended experiments, each test was performed twice, and the achieved separation performance values were measured.

Table 7. Responses of the mixture of oil-water

Run	Factor 1 d/w	Factor 2 α	Factor 3 Re Number	Response Separation Performance
1	0.017	10	4800	97.50
2	0.033	10	4800	97.42
3	0.017	50	4800	97.79
4	0.033	50	4800	97.71
5	0.017	30	3500	97.68
6	0.033	30	3500	97.63
7	0.017	30	6100	97.72
8	0.033	30	6100	97.64
9	0.025	10	3500	97.43
10	0.025	50	3500	97.74
11	0.025	10	6100	97.46
12	0.025	50	6100	97.77
13	0.025	30	4800	99.25
14	0.025	30	4800	99.24
15	0.025	30	4800	99.25
16	0.025	30	4800	99.23
17	0.025	30	4800	99.25

Within the scope of the study, the influence of the three parameters discussed for separation performance was analyzed. Consequently, for the optimization of the data, the plan was to conduct 17 experiments for system analysis. The separation performance values are shown in Table 7.

Table 8. Table of ANOVA for the mixture

Source	Sum of Squares	df	Mean Square	F value	p-value
Model (significant)	8.80	9	0.98	29.42	< 0.001
A- d/w	0.21	1	0.21	6.26	0.0407
B-α	0.67	1	0.67	20.07	0. 011
C- Re Number	2.000E-004	1	2.000E-004	6.016E-003	0.8201
AB	0.038	1	0.038	1.20	0.2890
AC	0.088	1	0.088	2.80	0.1183
BC	0.14	1	0.14	4.69	0.0470
A^2	2.32	1	2.32	72.58	< 0.001
B^2	2.58	1	2.58	75.49	< 0.001
C^2	1.93	1	1.93	57.63	0.003
R^2=0.9762					

Table 8 shows the ANOVA table for data in the evaluation and optimization of the parameters in the optimization program. The p-value of all parameters considered during the optimization process should be lower than 0.05 (Myers & Montgomery, 2002). The relevant table show whether, and how much, the considered parameters are effective in the separation operations. The parameter that affects the separation performance is the angle of mounting (α) of the corrugated plates to the separation unit. Also, the R^2 achieved as a result of the analyses is very close to 1 (0.9762), and it was concluded that the results achieved considering this value and the results of the applied model are compatible with one another.

The actual separation efficiency equation obtained as a result of the optimization is seen in equation 1. As can be seen from the related equation, treatment efficiency depends on the parameters considered. Each parameter affects the treatment efficiency both individually, squarely, and together with other parameters. It has been seen that when any value of each parameter is used in the obtained treatment efficiency equation, the treatment efficiency value obtained from the optimization and experimental results is obtained. Thus, the correctness of the relevant equation has also been proven.

<u>Final Equation in Terms of Actual Factors:</u>

$$\begin{aligned} Separation\ Efficiency = {} & 83.08620 + 825.53401 * \frac{d}{w} + 0.10827 * \alpha + 2.542454E * Re \\ & -0.61538 * \frac{d}{w} * \alpha - 0.013537 * \frac{d}{w} * Re - 4.55810E - 006 * Re * \alpha \\ & -17917.159 * \frac{d^2}{w} - 1.23520E - 003 * \alpha^2 - 2.24541E - 007 * Re^2 \end{aligned} \quad (1)$$

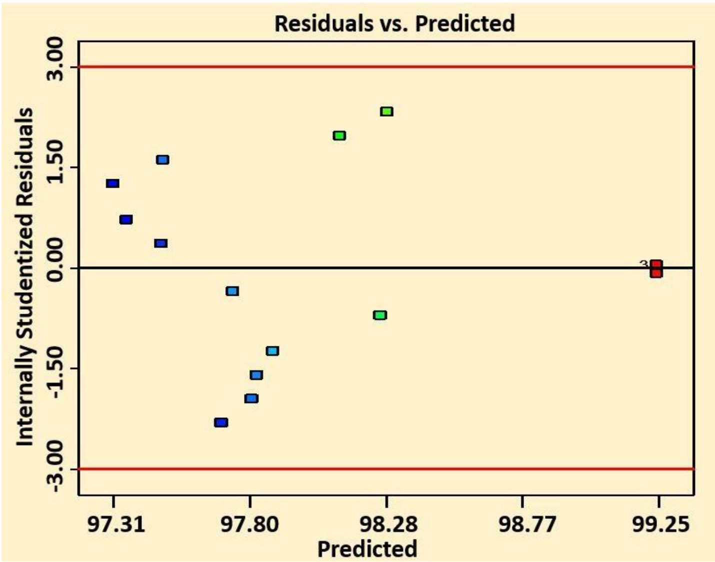


Figure 6. Graph of experimental vs. predicted responses for experiments.

Figure 6 shows that the residuals for the estimated separation performance values are normally distributed, proving that the quadratic model is compatible with the experimental values. The difference between the estimated and achieved separation performance values is an important factor to examine the adequacy of the model to predict the relevant outcome. When these results are evaluated, the separation performance values are true. Also, the balance of these data shows the precision and accuracy of the separation performance values measured as a result of all experiments.

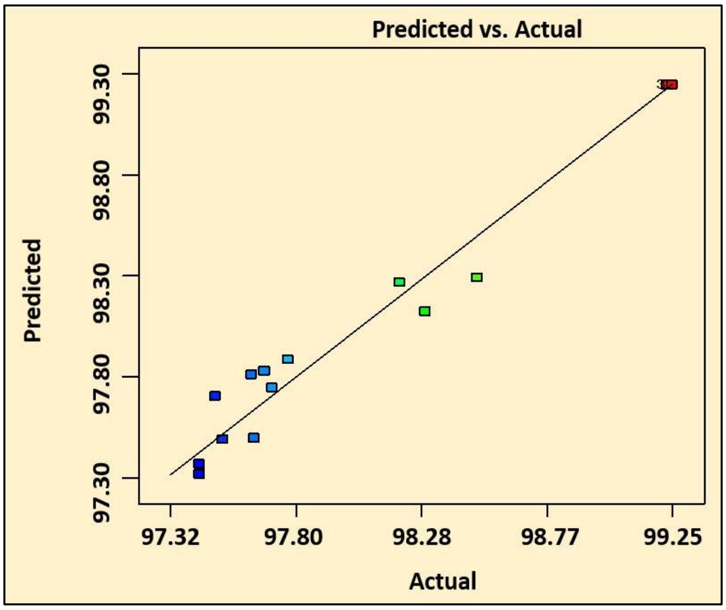


Figure 7. Predicted vs actual results.

The connection between the experimental results obtained using the sample and the estimated results of the model equation is shown in Figure 7. The obtained experimental results are in good agreement with the results predicted by the optimization model (Oruç & Yayla, 2022). In addition, the compatibility status proves the accuracy of the experimental results obtained (Yılmaz et al., 2021).

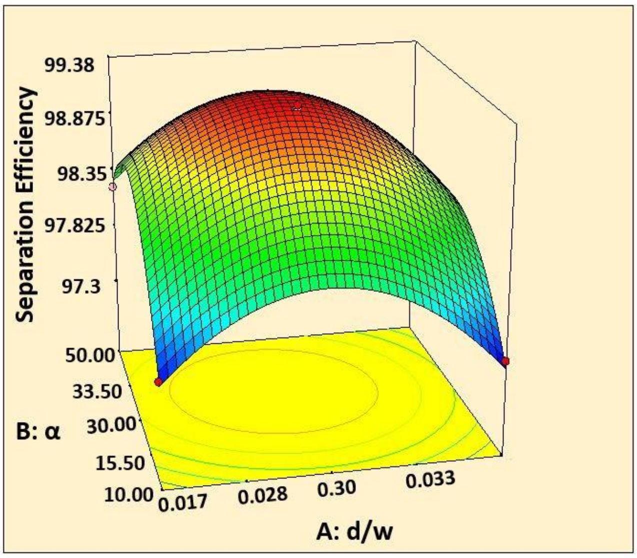


Figure 8. Effect of α and d/w on separation performance.

The separation performance values in the experiments were placed in the optimization design model. Also, the impact of the parameters included the study on the separation performance was analyzed. The impact of the mounting angle parameter in the separation unit and the d/w parameter on the separation performance can be seen in Figure 8. Increasing the angle of mounting up to 30-35 degrees increased the separation performance. However, the separation performance decreased at higher or lower values. The slope plates in the separation storage increases when the mounting angle value rises. When the degree of pitch increases, the fluid speeds up, and the flow speed of the mixture on the surface of the plates increases. When the value of the slope of the corrugated plates is increased, an increase in the fluid dynamic pressure occurs. The increase in dynamic pressure causes disturbances in the flow around the holes in the corrugated plate. These disturbances in the flow also contribute positively to the release of oil droplets and their adhesion to one another. This increases the separation performance. However, it is important to find the optimum parameter value since all of the parameters in the designed system are effective on one another. In defining the optimum d/w, the ability of adhering oil droplets to easily accumulate on the surface from the relevant holes and the mixture's flow rate are important during the separation process. During the separation operation, flow disturbance occurs due to the holes in the plates, and flow separation points are observed as a result of the disturbance. This event accelerates the adherence of oil droplets and the accumulation of oil droplets on the surface by moving upwards from the holes. For all these reasons, at low d/w values, there is a disturbance in the flow, for why the d/w is much low, and adherence of one oil droplet to another may take longer to rise to the upper level. However, the oil droplets that can't move to the surface are discharged without separation. On the other hand, flow separation points cannot occur if the d/w is higher than the optimum value, the count of holes will be lower, and enough separation will not occur in the fluid.

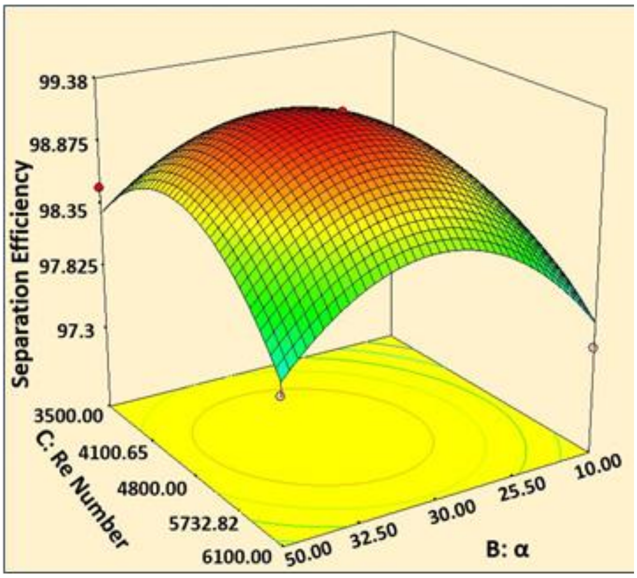


Figure 9. Effect of α and Re numbers on separation efficiency.

Figure 9 shows how the angle of mounting parameter of the corrugated plates inside the separation unit and the Re number of mixture pumped into the separation unit affects the separation performance. The flow mode changes from laminar to turbulent flow when the Re number of the mixture increases. The flow regime must be a transition zone regime during separation processes which use corrugated plates. The higher the flow turbulence level, the less likely oil droplets will stick one to another. Because of the turbulence flow model, the oil droplets adhere to one another poorly. Also, the droplets adhering to one another then separate from one another and are freed by the high effect of the forces in the vortex in the flow separation regions. The released oil droplets are also discharged along with the wastewater settling at bottom of the storage, resulting in low separation performance.

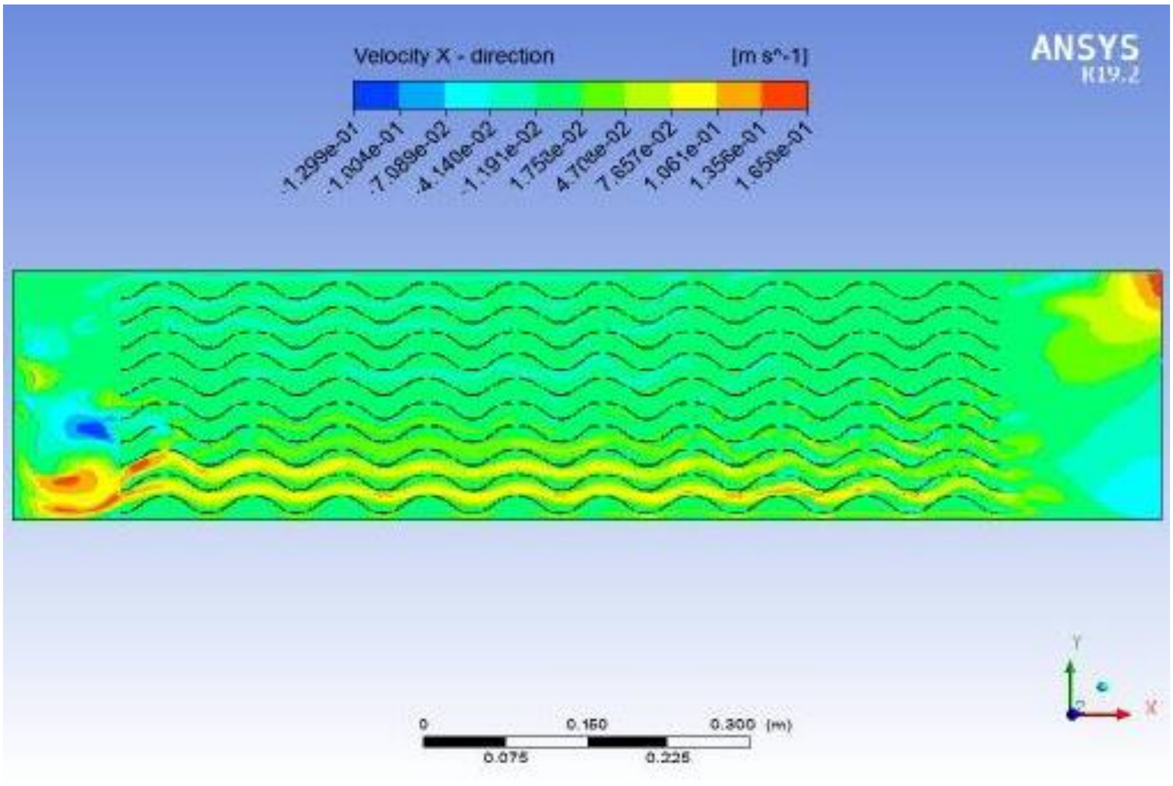


Figure 10. Re = 4800, α = 30 and d/w = 0.033 velocity profile.

As a result of the experiments, the highest treatment efficiency value was obtained as 99.38%. The experiment plan, in which the highest treatment efficiency was obtained, was simulated in the CFD program and the relevant experiment was utilized. In the end of the preliminary analysis, the treatment efficiency value was measured as 99.30% in the CFD program. Since the difference between the two results is negligible, the HAD results are considered. The optimization model suggested an experimental plan accordingly and the recommended experiments were performed in duplicate. At the same time, the recommended optimum experiment was carried out. As a result of the experiment, the highest separation performance was achieved. The experimental plan, in which the highest separation performance was achieved, was simulated in 2D and the plan was to obtain the same results numerically. The optimum test setup for the maximum separation performance was simulated in 2D and the related experiment was actualized numerically in the CFD program. The separation performance value achieved as a result of the experiment carried out agreed with the experimental result. Figure 10 shows the velocity profile of the mixture when the angle of mounting the corrugated plate to the separation unit is 30 degrees, the Re number of mixtures is 480045, and the d/w value of the plates is 0.030. As can be seen from the figure, while the velocity profile is high on the surface of the plates, the velocity of the mixture decreases as droplets move towards the surface. During the motion of droplets of oil towards the surface of the separation storage tank, horizontal and vertical flow motion occurs Because of the associated flow motions that occur, horizontal velocity decreases and a flow event can be observed in the mixture from underside of the separation storage tank to its surface.

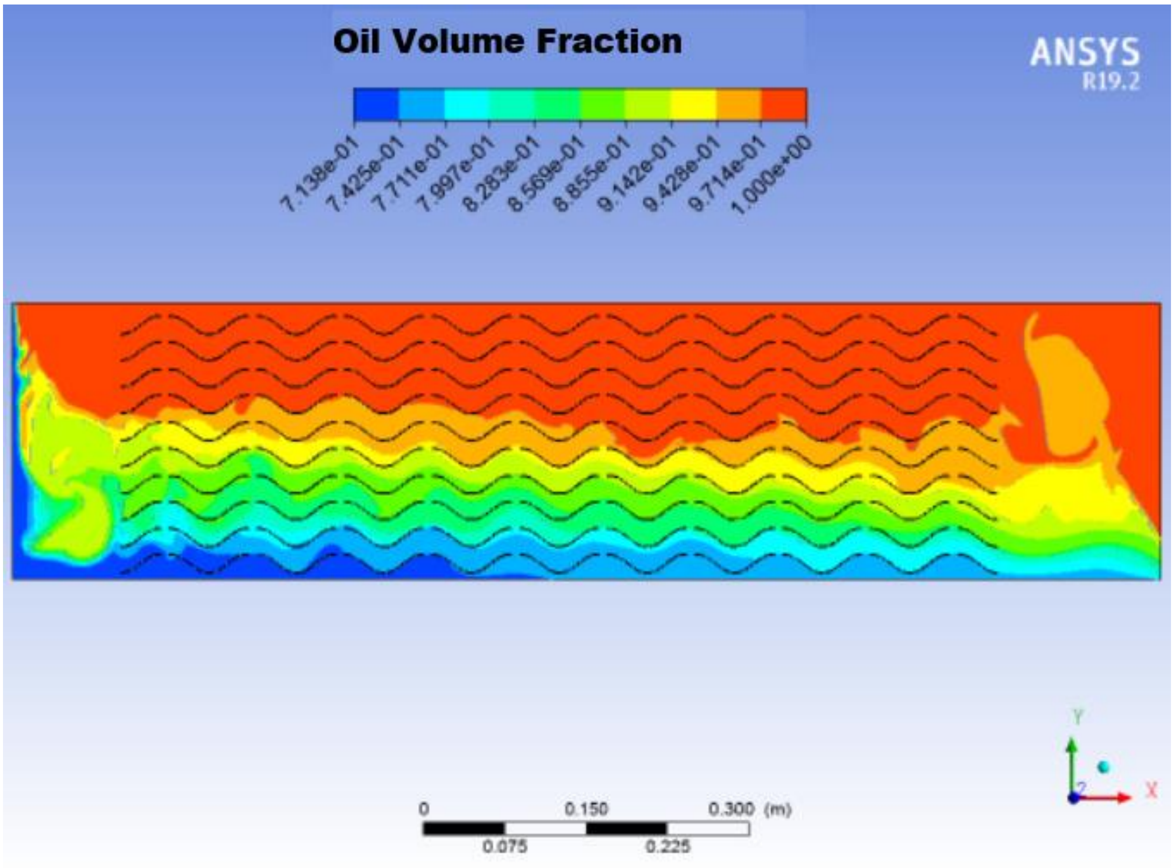


Figure 11. Oil volume fraction in optimum conditions.

The oil volume fraction achieved as a result of simulating the experimental setup under optimum conditions in the CFD program is shown in Figure 11. The separated oil accumulates on the surface, and the separated water comes together at underside of the storage tank.

4. Conclusion

In the study, an oil-water mixture sample was used, and the aim was to perform separation. In this context, studies were carried out based on 3 parameters (Re Number, d/w ratio, a) and 3 different values of each parameter. Evaluations were made for the dependent or independent effect of all parameters for the separation performance.

- It was observed that the Re number parameter influenced the separation performance. The highest separation performance was achieved when the flow regime is a laminar-turbulent transition regime. At the same time, it is possible to obtain the same separation performance with different Re numbers depending on the other parameters considered.
- The d/w parameter affected separation performance. It was observed that the d/w value of the plates increased the separation performance up to the optimum value and decreased the separation performance at higher values. It is important to determine the optimum d/w value at which the highest separation performance occurs throughout the separation, the flow rate of the mixture during the separation processes and the easy access to the surface of the oil droplets that adhere to one another and increase in volume through the holes on the surface of plates. Due to the holes in the plates the capacity of the oil droplets to stick to one another increases during the separation process, and the probability of the related oil droplets accumulating on the surface of the storage tank also increases. For this reason, it was concluded that determining the optimum value of the d/w ratio parameter is important in obtaining the maximum separation performance.

- The angle of mounting of the corrugated plates influences the separation unit with high effect on the separation performance both independently and dependently. As the pitch degree of the plates increases, the velocity of the fluid mixture also increases. With the aim of achieving maximum separation performance, this increase in speed must be kept at the optimum level. The main purpose is to increase the likelihood of the oil droplets in the mixture sticking together and to facilitate the rise of the related droplets to the surface.

When all the studies are examined, the parameters and their levels were chosen well. It is concluded that all parameters affect the separation performance both independently and dependently. The separation performance was achieved as a maximum of 99.30% when the mounting angle was 27 degrees, the d/w ratio was 0.02, and the Re number was 4800.

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NOMENCLATURE

Re	Reynolds Number	w	Width of Corrugated Plates
d	Hole Diameter of Corrugated Plates	A	Re Number
α	Mounting Angle of Corrugated Plates to Separation Unit	B	Hole Diameter of Corrugated Plates / Width of Corrugated Plates
RSM	Response Surface Method	C	Mounting Angle of Corrugated Plates to Separation Unit

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