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Statistical evaluation and Optimization of Crude Oil Desalting Unit: A Case Study of Bandar Abbas oil Refinery

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Abstract

Crude oil usually includes water, salty materials, suspended solids, and solvable metal particles. Desalting or dehydration is the first step in the refining process. This process is done to reduce or remove contaminants, corrosion, plugging and fouling of equipment. This paper investigates the effect of four factors (density, freshwater injection, heating, and mixing) on the efficiency of the dehydration/desalting process for Iranian crude oil and a commercial demulsifier (PETRO 1020 BA). These factors are systematically varied, and efficiency is analyzed. Two efficiencies are defined: a Salt Removal (S/R) efficiency and a Water Cut (W/C) dehydration efficiency. Statistical analysis of Plackett–Burman (P-B) along with response surface methodology (RSM) was used in the optimization process. The results showed that the high density of crude oil affects desalting/dehydration process adversely. Furthermore, it suggested that heating is the most important factor that improves efficiencies of S/R and W/C. The highest efficiencies were obtained at heating of 120˚C. The result of this research shows that the mentioned model has good agreement with experimental data.

Keywords: Crude oil emulsions; Dehydration/desalting; Crude oil treatment; Salt removal efficiency; Water cut efficiency.

Introduction

Desalting/dehydration facilities are often installed in crude oil production to minimize the presence of water in oil emulsions. The main goals of installing desalting plants are constant production rate in a field, decreasing the flow of salt content to refinery distillation feedstocks, reducing corrosion caused by inorganic salts and minimizing the energy required for pumping and transportation (Mahdi et al, 2008).

The desalting process includes six significant steps: separation by gravity settling, chemical injection, heating, the addition of less salty water (dilution), mixing and electrical coalescing. Gravity separation refers to the primary free settling of water and is related to the resident time that takes place in both settling tanks and desalting vessels. The gravitational residence time is calculated by the Stokes' law (Mahdi et al, 2008):

$$v = (2\pi r^2\ \Delta\rho g)/(9\mu) \qquad 1$$

From Eq. (1) gravitational separation can be increased by maximizing the size of a drop (chemical injection, electrical coalescing), maximizing density difference between two phases and minimizing viscosity of oil phase (heating, dilution)(Mahdi et al, 2008).

A conventional oil desalting plant consists of the separator, coalesce tank and electrostatic drum that are connected in series. The free water droplets are settled and separated from crude oil in the coalesce tank. Then, fresh water is mixed with crude oil to dilute base brine and decrease salt concentration. The prepared emulsion is fed to the electrostatic desalting drum and brine is separated from the crude oil. Among different desalination methods, the common method is electrostatic desalting that uses the electric field AC, DC, dual polarity, modulated dual polarity, electro-dynamic, and dual frequency are different common methods in electrostatic desalting (Aryafard

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et al., 2016).

Removal of corrosive water-soluble salts, particular chlorides of sodium and potassium from crude oil is an important processing operation in the refining of crude oils. The process of desalting usually involves addition 1–20% (w.) of wash water to the crude oil, mixing to form a W/O emulsion and then subjecting the emulsion to electrostatic demulsification or hydrocyclone treatment (Ye et al., 2010). Usually, emulsions are formed of water-in-oil (w/o). In the case of emulsions, when two droplets approach each other, the interfaces are separated by a thin film of oil. The emulsions must subsequently be broken down to recover the “clean” crude oil. Some of the oil fields have already got into the stage of secondary or tertiary oil recovery. The crude oil improved in this way tends to become ropier and more massive and contain more salts. It may be hard to desalt those oils with conventional methods by electric desalting and dewatering processes. The blackout of the desalting device and current collapse of the electric field usually happened. The oil pretreatment is discontinuous and unsteady. There is a great need of demulsification, and the impetus of developing new methods to have an effective treatment processing(Ye et al., 2008).

Over the past decades, some research have been conducted in emulsions with an aim to understand these complex systems. However, many unresolved issues remain. Oil–water emulsions include complex mixtures of organic and inorganic materials, all of which affect their behavior. These mixtures contain surface active materials which are responsible for the stability and integrity of the emulsion. They include asphaltene (bituminous materials), resins, phenols, organic acids, metal salts, mud, clay, and wax. The petroleum industry faces the challenge of resolving several types of complex emulsions on a daily basis. Production techniques result in stable crude oil-water emulsions which require aggressive treatment methods. The stability of the emulsion depends on a variety of factors introduced by the production process such as thermal and pressure cycles and energy input (Vafajoo, Ganjian, and Fattahi, 2012).

Ather common techniques have been improved for removing soluble and insoluble organic and inorganic contaminants from refinery wastewater, such as gravity settling separation and mechanical coalescence, coagulation and air flotation, electrostatic and electro coagulation separation. However, these methods would lead to a huge production of sludge and complicated operation problems. Membrane technologies have greatly used in separation facilities to separate liquid/liquid or liquid/solid mixtures due to the suitable pore sizes and capability of removing emulsified oil droplets and other organic contaminants. Ultrafiltration has been demonstrated as an efficient method of wastewater treatment, especially submerged membrane ultrafiltration that has been successfully applied to the refinery wastewater treatment. Thus, a stricter discharge standard is required to ensure the wastewater discharged is safe to the environments. For instance, in Malaysia, the effluent discharged from industrial sectors should comply with the national primary regulatory of discharged standard-Standard B (Yuliwati et al., 2012). The two most typical methods of crude-oil desalting, are chemical and electrostatic separation which use hot water as the extraction agent (Pak and Mohammadi, 2008).

Up to recently, ultrasonic irradiation was regarded as an efficient method of dehydration and desalting of heavy crude oil. Yu et al. used this method. To remove water from crude oil emulsion the in refinery processes. This was mostly done by deliberate injection of water into the crude oil to dissolve soluble salts especially NaCl.

Their experimental study on the impact of sound field parameters on the water in crude oil emulsion behavior showed that the efficient response of the dispersed water phase to ultrasonic irradiation to drive, coalesce, and segregate was similar to the behavior of a suspended particle, droplet, and bubbles in the sound field. If highly powered ultrasound is applied to an emulsion at low frequencies (<30 kHz), it can cause to split an emulsion into its component aqueous and oil phases (Check, 2014).

The difficulty in troubleshooting chemical plants increases with increasing plant complexity. Major damages and negative impacts on both plant's performance and human factors can occur when there is a delay in plant decision making. Henceforth, creating automated supervision that can identify faults precisely in an efficient manner is necessary for the safe and economic operation of complex plants. Systematic and consistent troubleshooting reduces operator errors and consequently, decreases maintenance and repair time. A crude oil desalination process is a complex plant which includes large, multipart and complex stages. Therefore, performing a correct troubleshooting method is an essential matter to prevent any unpredicted shutdown. Fuzzy troubleshooting (FT) provides a systematic method for diagnosing by incorporating expert knowledge acquired from experts or plant manual. The use of fuzzy expert system provides means for dealing with an uncertain situation when existing knowledge is ill-defined (Mahdi et al, 2008). A fuzzy expert system is also protected from all human emotions, like stress, and exhaustion, that can cause deficiency while troubleshooting (Zahedi et al., 2011). Actually cost for each method of Desalination systems depends mainly on type of physical process of salt removal (i.e. evaporation, filtration, freezing or electrostatic potential difference) (Khoshrou, Jafari Nasr and Bakhtari, 2017).

These studies denote that the effect of process variables is very complicated. Conducting experiments to evaluate and study the effect of parameters on a real plant is costly and time-consuming. Especially, the governing laws usually prohibit changing parameters in a real plant and normally it is difficult due to operational limitations.

The main objective of this study is to investigate the effects of four different process variables, i.e., fresh water injection, temperature, a differential pressure of mixing valve and density on the performances of two-stage desalter based on the approach of RSM (Design expert® 7.0.0). The experimental runs were designed by the central composite design and carried out batch-wise. All the experiment used in this study was prepared based on American Society for Testing and Materials or ASTM.

Response surface methodology (RSM), a collection of mathematical and statistical techniques is a useful tool for experimental design, model development, the evaluation of factors, and the optimization of conditions. Statistical optimization reflects the role of each component of the process. Response surface methodology allows not only the determination of optimum conditions but also the analysis of how sensitive the optimum conditions are to variations in experimental variables. The application of RSM to design optimization aims to reduce the cost of expensive analysis methods. Another advantage of RSM is that it is possible to make different projections, which provide graphic illustrations, thus allowing a visual interpretation of the functional relations between the response and experimental variables (Rastegar et al., 2011). Meanwhile, use of RSM has gained prominence in food process design and optimization owing to the ease of operation, reliability, and reproducibility of the model parameters. Nowadays, factorial designs have proved their usefulness, and are widely used in the statistical planning of experiments to obtain empirical models relating process response to process factors (Onsekizoglu, Savas Bahceci, and Acar, 2010).

Material and Methods

Operating plant

Fig. 1 represents the process flow diagram of a real typical of two-stage electrostatic desalting. In two-stage desalting technology in Bandar Abbas oil refinery, outlet water from the second desalting drum is mixed with crude oil to dilute the base brine and decreasing salt concentration in the emulsion. The size distribution of outlet droplets from the valve is a function of mixing pressure drop, the residence time of emulsion in the valve, temperature and feed property such as viscosity and density. Then, a feed is entered to the first desalting drum and distributed uniformly through a distributor. Emulsion moves toward the top of the horizontal drum and is entered to the alternative current (AC) electric field section. An electrical system connected to the electrodes generates an electrostatic field at a potential about 20,000 volts and induces attractive dipole force between neighboring water droplets. AC electric field causes a dipolar attraction force between droplets and improves collision and coalescence efficiency of water droplets. Smaller droplets move up with the crude oil as a continuous phase, and the larger drops move down because of the dominant gravitational force compared to upward drag force. Outlet crude from top of the first desalting drum is mixed with fresh water to dilute the brine so the target salt content can be achieved by the crude oil dehydration. In the next stage, the large drops move downward and coalesce. The processed crude oil leaves the top of the vessel, and the settled sediment at the bottom of drums is withdrawn as sludge (Aryafard et al., 2016).

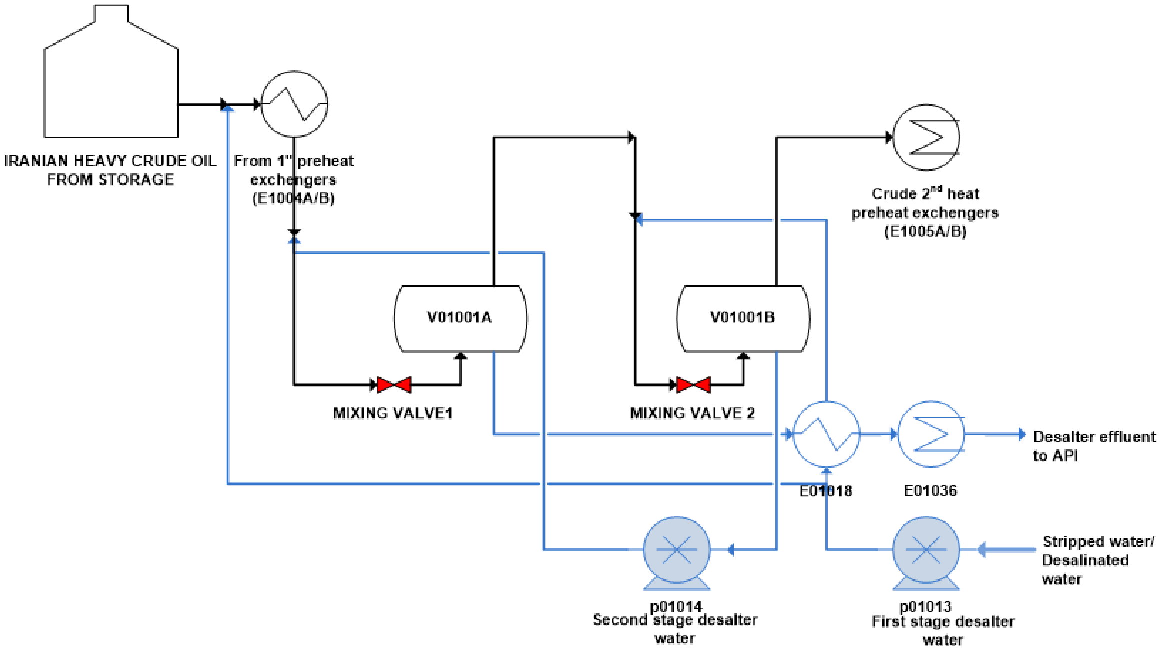

Figure 1: Process flow diagram of two-stage electrostatic desalting.productivity.

Experimental

National Iranian Oil Company (NIOC) supplied crude oil, collected from the Kharg and Hengam oil wells. The characteristics of this crude oil are illustrated in Table 1. The chemical used as a demulsifier in the experiment is under the trade name PETRO 1020 BA supplied by Petro Puyesh Kimiya company. In carrying out the experiments, crude oil samples were first analyzed for the salt result (S/R) in PTB and water cut (W/C) in volume percent. Firstly, freshwater was added, followed by the addition of demulsifier. The mixture was then heated in a water bath heater. The heated mixture was then mixed and poured into a 100-mL centrifuge tube and rotated at a speed of 1000 rpm. The final step in completing one cycle was to collect the top crude volume in the centrifuge tube and to test it for S/R and W/C. The top volume was taken because, in the real operation process, the treated crude, after mixing and heating come out from the top of the desalting vessel. In a real process, an emulsion that was introduced into the system was subjected to freshwater injection followed by chemical dosage. The mixture, emulsion, freshwater, and chemical were then heated to a certain temperature and then mixed. The resulting blend was sent to a settling tank where water and salt are to be drained off. At the final stage of the process, dry or treated crude oil samples were tested and analyzed for S/R and W/C. In each cycle of the experiment, a sample of crude oil to be tested was taken in a sample tube or graduated cylinder of about 100 mL. Then both freshwater and chemical demulsifier were added according to previously set ranges. Crude oil, freshwater, and chemical were next heated and then mixed for a certain time (min). Then, the mixture was taken to a centrifuge where it was rotated for settling purposes. From the top of the centrifuge tube, a certain volume of dry crude was with drawn by a micro milliliter syringe and then transferred to a test beaker. The S/R test was conducted on a partial volume of that dry crude (about 10 mL), and then 50 mL was transferred to a centrifuge for W/C test (Mahdi et al, 2008).

Table 1: Characteristics and specification of crude oil samples

Oil/combination	Density (kg/m3)	Asphaltene (wt%)
Kharg crude oil	896.4	2.17
Hengam crude oil	823.4	0.499
95% (Kharg crude oil) + 5% (Hengam crude oil)	889	2.092
90% (Kharg crude oil) + 10% (Hengam crude oil)	885.6	2.014
85% (Kharg crude oil) + 15% (Hengam crude oil)	882.1	1.936
80% (Kharg crude oil) + 20% (Hengam crude oil)	878.6	1.857
75% (Kharg crude oil) + 25% (Hengam crude oil)	875.1	1.777
70% (Kharg crude oil) + 30% (Hengam crude oil)	871.7	1.697
65% (Kharg crude oil) + 35% (Hengam crude oil)	868.2	1.616
60% (Kharg crude oil) + 40% (Hengam crude oil)	864.7	1.534

Design Expert version 7.0.0 statistical software was used in analyzing the results. According to The CCD of RSM with a total of 30 experiments,

the four factors made up of Fresh water injection, Temperatur, DP mixing valve desalter B, and Crude oil density were used in this study. The minimum and maximum range of variables were investigated, and the full experimental plan concerning their values in actual and coded form was listed in Table 2. The actual values of the four independent variables with the responses are summarized in Table 3.

Table 2: Independent variables and limit level for response surface study.

Variables	Unit	Symbols	Levels				
			-2	-1	0	1	2
Fresh water injection	m^3/h	A	6	12	18	24	30
Temperature	^0C	B	60	80	100	120	140
DP mixing valve desalter B	mbar	C	700	925	1150	1375	1600
Crude oil density	kg/m3	D	830	840	850	860	870

Table 3: Experimental layout designed Based on the CCD.

Standard	Factor variables				Responses	
	Fresh water injection	Temperature	DP mixing valve desalter B	Crude oil density	outlet salt%	Outlet Water & Sediment%

	m^3/h	^{0}C	mbar	kg/m3		
1	12	80	925	840	2.2	0.48
2	24	80	925	840	1.5	0.72
3	12	120	925	840	1.3	0.24
4	24	120	925	840	0.6	0.48
5	12	80	1375	840	1.7	0.24
6	24	80	1375	840	1	0.48
7	12	120	1375	840	0.8	0.1
8	24	120	1375	840	0.1	0.24
9	12	80	925	860	2.8	0.64
10	24	80	925	860	2.1	0.88
11	12	120	925	860	1.9	0.4
12	24	120	925	860	1.2	0.64
13	12	80	1375	860	2.3	0.4
14	24	80	1375	860	1.6	0.64
15	12	120	1375	860	1.4	0.16
16	24	120	1375	860	0.7	0.4
17	6	100	1150	850	2.5	0.24
18	30	100	1150	850	0.7	0.64
19	18	60	1150	850	2	0.68
20	18	140	1150	850	0.8	0.24
21	18	100	700	850	1.8	0.56
22	18	100	1600	850	0.8	0.28
23	18	100	1150	830	0.7	0.16
24	18	100	1150	870	1.7	0.52
25	18	100	1150	850	1.2	0.4
26	18	100	1150	850	1.1	0.4
27	18	100	1150	850	1.1	0.4
28	18	100	1150	850	1.1	0.4
29	18	100	1150	850	1.1	0.4
30	18	100	1150	850	1.3	0.32

Choosing an appropriate model in describing the shape of the surface is of vital importance.

To identify the best model fitting the data, it can be started with the most straightforward model forms like first- and second-degree Scheffe's polynomial. In this study, the quadratic model used for predicting the optimal point.

Results and Discussion

Screening of the compelling factors by the Plackett–Burman design

The adequacy of the model was calculated, and the variables showing statistically significant effects were screened via their ANOVA p-values (Amiri et al., 2012). The results of P-B in estimating effects of variables with the software (Figure2) indicated that Freshwater injection, Temperature, DP mixing valve desalter B and Density were the significant variables on desalting, and Temperature, Freshwater injection, DP mixing valve desalter B and Density were the considerable variables on dehydration and Caustic injection to desalter B had less effect. Therefore, these variables were selected for experimental design by RSM. Except for the density, the other three essential variables had adverse results (Figure 2) on desalting/dehydration, as the decrease in their content raised on the output oil from desalting. All other insignificant variables were neglected, and the optimal values of the four variables were further determined by CCD design (Mohammad Mirzaie et al., 2016).

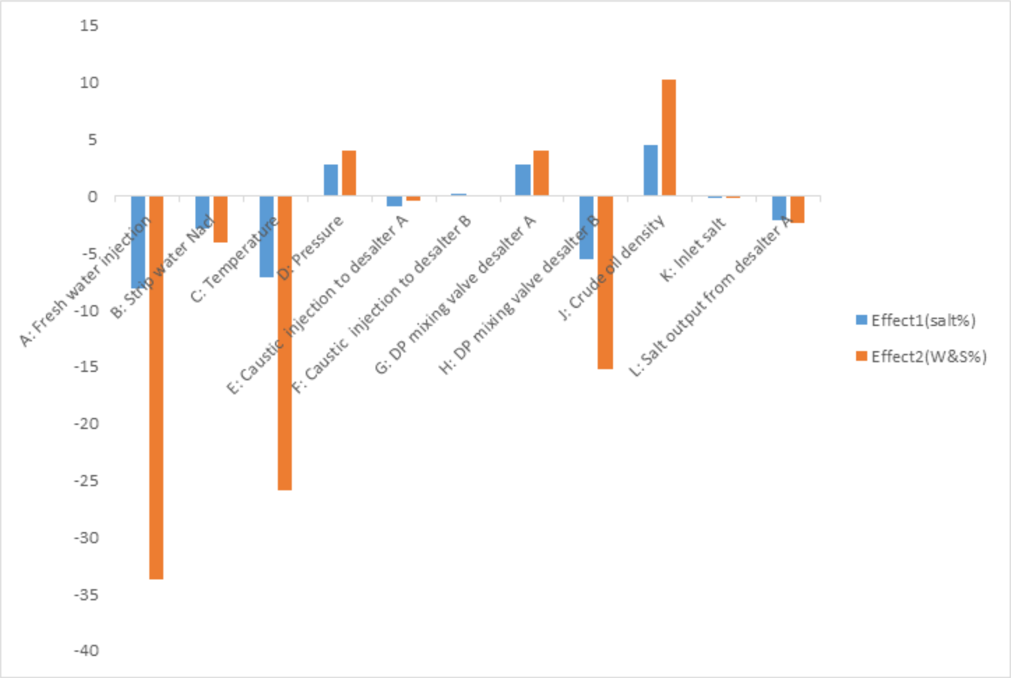

Fig. 2: Statistical modeling and optimization using RSM

Experimental design

The designs were based on two-level full factorial design, which was augmented with center and star points. To identify the goodness-of-fit, Model fitting to equation of up to the fourth-order polynomial was performed. Multiple regression was used to fit the response to the variables and ANOVA was used to subdivide the total variation of the data set into Component parts associated with the specific sources of variances for the purpose of testing hypotheses on the parameters of the models. The ANOVA of these models have demonstrated that the model is highly significant as is evident from Table 4 which tabulated the effects and interactions of freshwater injection, Temperature, DP mixing valve desalter B, and Crude oil density on salt and water & sediment content in desalted crude oil of refinery desalting (Yuliwati et al., 2012).

Table 4: ANOVA for Response Surface Quadratic Model (partial sum of squares — type III) responses: Salt and W%S

	Sum of		Mean	F	p-value	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F	Squares	df	Square	Value	Prob > F
					Salt%					W&S%
Model	11.33	14	0.81	48.24	< 0.0001	1.01	14	0.072	40.97	< 0.0001
A	3.53	1	3.53	210.2	< 0.0001	0.29	1	0.29	162.7	< 0.0001
B	3.84	1	3.84	228.87	< 0.0001	0.3	1	0.3	172.8	< 0.0001
C	1.5	1	1.5	89.4	< 0.0001	0.24	1	0.24	134.3	< 0.0001
D	1.93	1	1.93	114.83	< 0.0001	0.15	1	0.15	85.57	< 0.0001
AB	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
AC	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
AD	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
BC	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
BD	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
CD	0	1	0	0	1	0.000625	1	0.00063	0.36	0.5599
A^2	0.43	1	0.43	25.54	0.0001	0.00943	1	0.00943	5.36	0.0351
B^2	0.15	1	0.15	9.2	0.0084	0.015	1	0.015	8.65	0.0101

C^2	0.069	1	0.069	4.09	0.0614	0.00503	1	0.00503	2.86	0.1114
D^2	0.017	1	0.017	1.02	0.3281	0.001144	1	0.00114	0.65	0.4324
Residual	0.25	15	0.017			0.026	15	0.00176		
Lack of Fit	0.22	10	0.022	3.1	0.1121	0.021	10	0.0021	1.97	0.2349
Pure Error	0.035	5	7.00E-03			0.005333	5	0.00107		
Cor Total	11.58	29				1.03	29			
Std. dev.	0.13		R2		0.9783	0.042		R2		0.974
Mean	1.37		Adjusted R2		0.958	0.43		Adjusted R2		0.9507

Values of ‘ProbNF’ less than 0.0500 indicate model terms are significant.
a Significant.
b Not significant.

Statistical testing using Fisher's statistical test for ANOVA was employed for the determination of significant variables where the degree of significance was ranked based on the value of F-ratio. As the matter of fact the larger the magnitude of F-value and correspondingly the smaller the ‘ProbNF' value, the more significant is the corresponding model and the individual coefficient (Chen et al., 2010; Khouni, Marrot and Ben Amar, 2010; Cui, Chang and Fane, 2003; Ueda, Hata and Kikuoka, 1996; Montgomery, 2017; Gunst, 1996). It was observed from ANOVA analysis (Table 4) that the confidence level was greater than 80% ($P<0.05$) for the salt response while F-value and P-value of the model were 48.24 and 0.0001 respectively. This indicated that the estimated model fits the experimental data adequately. Also shows the confidence level of ANOVA analysis of Water & Sediment response which was greater than 80% ($P<0.05$) for Water & Sediment response while F-value and P-value of the model were 40.97 and 0.0001 respectively. This also indicated that the estimated model fits the experimental data adequately.

The p values of the model factors are shown in Table 4. Those p values less than 0.05 revealed that the effect of the model factor is significant. According to the p values in Table 4, factors A (fresh water injection), B (temperature), C (DP mixing valve desalter B), and D (crude oil density) were all significant parameters, and A^2, B^2 was also taken as significant terms for salt and water & sediment content in desalted crude oil. The coefficient of determination (R^2) value of the presented model for salt and water & sediment content is shown in Table 4. Figure 5 shows the predicted values versus experimental results of the productivity. The represented models based on the significant terms as a function of the coded factors are as follows:

Salt content = $1.15 - 0.38A – 0.4B – 0.25C + 0.28D + 0.31A^2 + 0.075B^2$

W&S content = $0.39 + 0.11A - .11B - 0.099C + 0.079D + 0.019A^2 + 0.024B^2$

The responses predicted by the model were in agreement with the experimental values. This was demonstrated by plotting the predicted values against the experimental values. Fig. 3(a,b) shows the plots for predicted versus actual values for salt and W&S in desalted crude oil. These plots indicate adequate agreement between the real data and that obtained from the models and demonstrated that the model is suitable for explaining the experimental range studied.

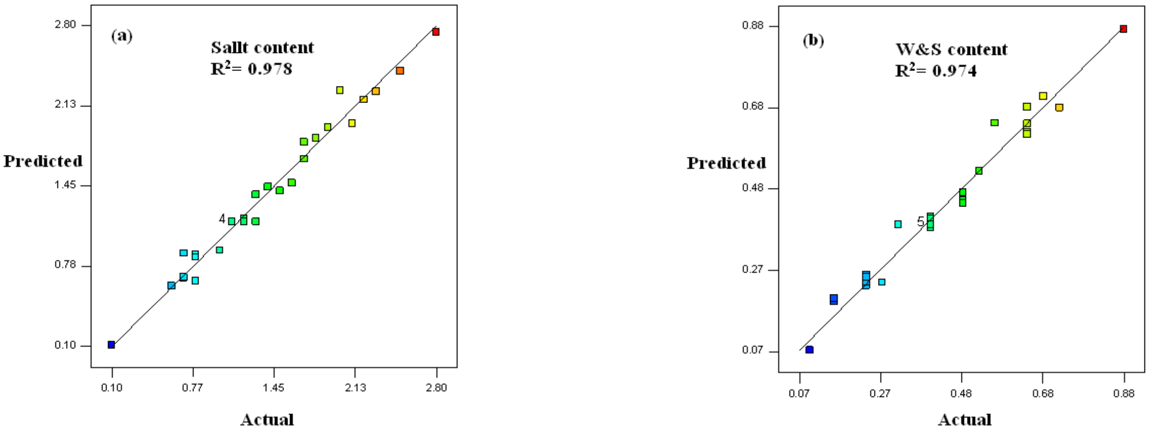

Fig. 3: Predicted vs. actual values plot for (a) salt and (b) W&S in desalted crude oil.

The response surface plots for salt and water & sediment content are shown in Figure 4. Figure 4a shows the simultaneous influence of freshwater injection (A) and temperature (B) on salt content when the DP mixing valve desalter B and crude oil density is kept in its center level of 1150 mbar and 850 kg/m^3 respectively. Figure 4b shows the simultaneous influence of DP mixing valve desalter B (C) and crude oil density (D) when fresh water injection (A) and temperature (B) is kept in its center level of 18 m^3/h and 100 $^{\circ}$C respectively. Figure 4c shows the simultaneous influence of fresh water injection (A) and temperature (B) on water & sediment content when the DP mixing valve desalter B and crude oil density is kept in its center level of 1150 mbar and 850 kg/m^3 respectively. Figure 4d shows the simultaneous influence of DP mixing valve desalter B (C) and crude oil density (D) when fresh water injection (A) and temperature (B) is kept in its center level of 18 m^3/h and 100 $^{\circ}$C respectively. According to the figure 6a figure 4b, the lowest salt content could be obtained in the down of the surface. The down of the surface in these figures is higher levels of fresh water injection, temperature, DP mixing valve desalter B and lower level of crude oil density factor. Perhaps increasing or decreasing factors outside of the range have a negative effect on the salt content. This seems reasonable due to the effects of these factors on salt content. Meanwhile, the productivity for each combination of factors could be measured from the figures.

The simultaneous influence of the factors for the W&S content is shown in Figure 4c Figure 4d.

A similar discussion for salt content can be made on the surface plot of W&S material. It should be noted that higher levels of temperature, DP mixing valve desalter B and lower levels of fresh water injection and crude oil density resulted in the reduction of W&S content. According to the results, the temperature lays the most important role in the desalting plant.

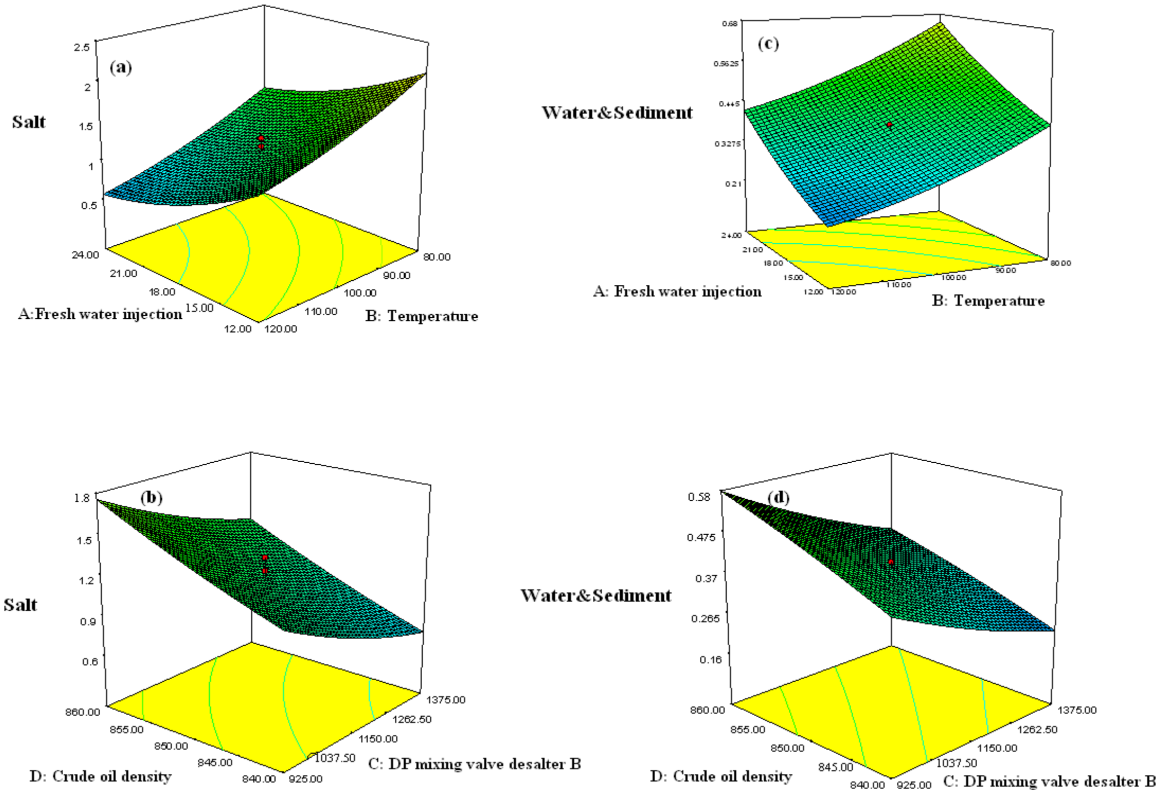

Fig. 4: Response surface of salt and water & sediment content in desalted crude oil depending of variables.

As mentioned above the efficiency of desalting in each experiment is determined by measuring the salt result and the water cut. We first considered changes in a response produced by a change in the level of each factor. The individual effect of each factor at different levels was cross-plotted against S/R and W/C efficiencies as shown in Figure 4. Besides, we have also considered multiple effects of changing factors simultaneously.

Temperature effect

Heat causes a decrease in viscosity, thickness, and cohesion of the film surrounding water drops. Heat also reduces the continuous phase (oil) viscosity, helping water drops to move freely and faster for coalescing. Controlling the temperature during operations is a very delicate job. Any excessive heat might lead to evaporation, which results not only in a loss of oil volume but also in a reduction in price because of a decrease in the API gravity (Al-Otaibi et al., 2003).

Liquid density and viscosity usually decrease with temperature. This means that increasing operation temperature will raise settling rate and therefore, improve separation. In a given desalter, separation improvement means that a larger quantity of oil can be desalted at the same time. This would suggest that a higher temperature is more convenient. However, crude oil conductivity increases with temperature and so does the power requirement of the process. Additionally, higher temperatures imply an increase in heating costs. Given these opposing facts, it is expected that there is an optimum temperature. In the case of Iranian heavy crude oil feedstock, it was necessary to know the dependence of effective parameters on the temperature to determine if an optimum temperature exists (Fetter Pruneda, Borrell Escobedo and Garfias Vázquez, 2005).

Dilution with freshwater effect

It is obvious that salt removal from crude oil is directly proportional to the amount of wash water although the lower values of demulsifier amount and operational temperature (Sellami, Naam and Temmar, 2016). Salts in emulsion sometimes come in solid crystalline form. So, the need for freshwater to dissolve these crystal salts arises, and dilution with freshwater has become a necessity in desalting/dehydration processes. Freshwater is usually injected before heat exchangers to increase the mixing efficiency and to prevent scaling inside pipes and heating tubes. Freshwater is injected so that water drops in emulsions can be washed out and then drained off. Hence the term ‘‘wash water." The quantity/ratio of freshwater injected depends on the API gravity of the crude, but, generally, the injection rate is 3-10% of the total crude flow. To improve the efficiency of W/C, the wash water injection must be operated at the optimum point. Beyond that point, experience has shown that excessive water may lead to deterioration in the pH range of the water volume as a whole. Ranges of pH above or below 7.0 may cause severe problems in emulsion breaking and precipitation of hydrocarbon solids (e.g., naphthalene) into the continuous water phase (Al-Otaibi et al., 2003).

Oil viscosity effect

The resistant force against the approaching move of the water droplets is known as the film thinning force, which mainly depends on the oil viscosity. A well-known fact among the workers in petroleum dewatering and desalting units is that water separation in the summer is more effective than winter. This refers to the rigorous temperature dependency of oil viscosity, as the oil viscosity is reduced at higher temperatures, the film thinning force declines and water droplets coalesce easier (Mohammadi, Shahhosseini and Bayat, 2012).

Mixing effect

Mixing is used in a desalting/dehydration process to promote further dispersion of dilution water and demulsifier/chemical with the emulsion. It is also used to help smaller water droplets coalesce, enhancing the S/R efficiency and, in particular, affects the W/C efficiency. High shear actions form emulsions. Similarly, when dilution water (freshwater) is added to an emulsion, one needs to mix them to dissolve the salt crystalline and to aid in coalescing finely distributed droplets. Mixing works in three steps: (1) helps smaller drops to join together, (2) mixes chemical/demulsifier with the emulsion, and (3) breaks the free injected volume of wash water into emulsion-sized drops and evenly distributes it (Al-Otaibi et al., 2003).

Conclusion

In this study, desalting/dehydration process was investigated to remove water-soluble salts from an oil stream. To minimize water-soluble salt, the desalter unit was optimized using statistical analysis of Plackett–Burman (P-B) and response surface methodology (RSM). This research reflects the results of a conducted research regarding the impact of operational desalting parameters, including the effects of temperature, fresh water injection, and differential pressure of mixing valve related to desalter B and density of crude oil, in an industrial two-stages electrostatic desalting process on one of the oil refinery owned by the Iranian Oil Company in Bandar Abbas. The developed model for salt and water & sediment content responses was statistically validated by analysis of variance (ANOVA) which showed a high value coefficient of determination value ($R^2 = 0.97$). The obtained optimum operating parameters were found to be 120 $^{\circ}$C of temperature, wash water rate of 19.40 m^3/h, DP mixing valve 1375 mbar and crude oil density 840 kg/m3. Under these conditions, the salt and water & sediment content in desalted crude oil was 0.28% and 0.17% respectively. The predicted results were compared with the experimental ones. In general, the predicted values were in reasonable agreement with the experimental data, further confirming the very good prediction ability of the models.

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