Application of Electric Mixing Method to Increase Industrial Crude Oil Dehydration Efficiency

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Abstract
The salt can reason severe difficulties like fouling, corrosion using salt deposition and catalysts poisoning in the downstream parts. In this study presents a modification process for improving efficiency of dehydration in a desalting unit. The main purpose of this investigation is to substitute the mixing valve by an electrical mixing system. Process configuration was modeled in addition to the electrostatic desalting drum. Based on this model, it is affirmed that modification is capable to increase efficiency of dehydration. The models are designed according to the population balance technique to predict water cut in treated crude oil. In order to improve the considered model accuracy, the consequences are compared to industrial data of mixing valve. The comparison between the results gained by the mixing valve and the electric mixing system proves the superiority of suggested tool. Furthermore, the results indicate the electric field strength optimum value in mixing step to attain minimum water cut in treated crude oil.

Keywords: Crude oil; Oil/water emulsions; Mixing method; Method of class; PSD.

1. Introduction
Crude oil is a kind of complicated mixture and commonly contains water and a large quantity of salts. For separating water-in-oil emulsions chemical demulsifiers and gravitational settlers are very common in industry. The extracted crude oil from reservoir involves some substance such as solid particles, salt, water and gas. The crude oil of a reservoir may include several amount of H\textsubscript{2}O, dissolved salt and sediments. Mineral salts maybe existing in oil in numerous forms like emulsified and dispersed crystal and water. Oil dehydration and desalting systems are processes to remove water soluble salts of the oil stream. Also, the main objective of a desalting of crude oil is to attain enough product in relations of water cut and salt removal efficacies. Subsequently,
to prevent and reduce the mentioned difficulties, installation of dehydrating and desalting facilities is required [1].

Water breaks in small droplets due to shear forces from fractures and pores in production unit. This phenomenon may result in the intense mixing of oil and water that breaks the droplets to make smaller ones by the average diameter about 10µ [2]. The next significant factor in formation of emulsion is presence of emulsifier. Emulsifiers stabilize emulsions using surface-active agents (surfactants). Surfactants have two main parts in their molecular structure, a hydrophilic part that is dissolved in water and a hydrophobic part which dissolves in oil [3]. Because of this dual structure, the surfactants attack the oil-water interface, which leads to lowering the interfacial tension and promotes the emulsification of the droplets. To date, various approaches have been applied to increase the separation of water/oil emulsions that could be classified in four groups: electrical, thermal, mechanical and chemical approaches [4]. Electrostatic desalting stages are applied extensively to reduce water cut and salt in crude oil because of their low energy consumption and high inefficiency [5]. The desalting process contains two steps. The first step is water dilution and emulsification and the second step is electrostatic coalescence and separation. Usually, utilizing an electrostatic field can increase coalescence unit.

Many researchers have concentrated on water separation from the crude oil system. Mahdi and coworkers [6] analyzed influence of concentration of demulsifier, temperature, settling time, wash water dilution ratio and mixing time by wash water on performance of desalting process. The demulsifier concentration optimum values, rate of wash water and temperature were to be 16 parts per million, 10% and 78 °C, respectively. Vafajoo and coworkers [7] studied the influences of inoculated chemicals, pH, and temperature on the crude oil deemulsification in the electrostatic desalter stage. The obtained consequences indicated to achieve high desalting efficiency, a temperature must be in range 115-120 °C. Abdul-Wahaband coworkers [8] used an inferential measurement to find out relationship among the input and output variables in the desalting unit. The input variables were dilution rate, chemical dosage, mixing time, settling time and temperature and output variables were salt removal and water cut efficacy. Al-Otaibiand coworkers [9] modeled and optimized an industrial desalting process using artificial neural network (ANN). The ANNs were selected because their potential to model very nonlinear relationships of the parameters of desalting/dehydration system. Bresciani and coworkers [10] suggested the detailed model according to cellular automata idea by the balance of force colorations of physical process including coalescence sequence of droplets. Mitre et al. [11] predicted water droplets PSD and suggested a novel breakage model. Aryafard and coworkers [12] studied the electrostatic drum and the industrial mixing valve. They studied the parameters of controlling influences like fresh water rate and the mixing valve pressure drop. The simulation results indicated an increasing in the fresh water flow rate from 4% to 7% leads to decrease content of salt in crude oil of 2.07 to 0.72 pounds of salt per thousand barrels of crude oil.

Population balance equations (PBEs) have been presented in numerous branches of science, mainly in chemical engineering field, to define the population of particles evolution. Population
balance equations, more usually, define how separate entities populations develop in specific features over time. The population balance method was first presented using Hulburt and Katz [12]. Rather than adopting the standard continuum mechanical framework, the model derivation was according to the alternative Boltzmann-type equation familiar from classical statistical mechanics. The key problems studied stem from solid particle agglomeration, growth and nucleation. The main purpose of this comminution is modification of mixing stage for improve the desalting efficacy in crude oil desalting stage. It is shown an electric field can be applied to combination crude oil and dilution water at high efficacies in the emulsification unit. Consequently, mixing valve section is substituted by electric mixing. Also, desalting process and suggested emulsification technique was explained in details. The conventional and suggested processes are modeled according to population balance technique at steady-state condition. In the next section, the numerical technique is proposed to solve obtained equations.

2. Electrostatic behavior

The main stream of electrostatic desalters include the few public elements like sand jetting system, collector pipe, vessel containment, pressure, power units, electrode grids and inlet distribution system. The used electric field can have categorized as direct current (DC) and alternating current (AC), alternating field and direct combination [13]. In alternating current, water droplets shape variations from oval to round and vice versa because of varying potential. Furthermore, the coalescence of water droplets is better due to attraction forces among two ends of oppositely charged droplets of water. Because of changing polarity, droplets just shake in place of moving. Though, AC treaters are very effective for bulk water removal due to the dipolar attraction phenomenon. In the low water cut crude oil case, space among droplets growths consequently attraction of dipolar decreases. Lately, high frequency alternating current modulated and technology high frequency alternating current method have been presented to increase the presentation of alternating current desalters. As droplets contact the electrode, the droplets are electrically charged and move opposite electrode because of electron transfer. It is notable that direct current method cannot be applied for the high aqueous phase include emulsions because of electro corrosion propensity [12, 13].

2.1. Electrostatic force

In the electrostatic desalter the electrostatic forces could be categorized as dipolar attraction forces, electrophoresis and dipolar attraction forces. Dipolar attraction is an attraction force among opposite charged ends of droplets. Dipolar attraction is the main mechanism in the AC electrostatic desalters. Electrophoresis is the electrical force among electrode and charged water droplets in a uniform electric field which, happens just into the direct current desalters. Figure 1 and Table 1 indicates strength of electrophoresis and dipolar force and compared to the droplets weight.
Table 1. The electrostatic forces in the voltage field.

<table>
<thead>
<tr>
<th>Field Voltage</th>
<th>Dipolar Attraction</th>
<th>Electrophoretic Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direction</td>
<td>Force</td>
</tr>
<tr>
<td>Alternating Present</td>
<td>Oscillates</td>
<td>0.39</td>
</tr>
<tr>
<td>Direct Current</td>
<td>Constant</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Fig. 1. Electrostatic forces.

The desalting procedure is accomplished in as following main stages:

- Injection of fresh water.
- Mixing of emulsion and fresh water using a mixing valve.
- New emulsion distribution in drum.
- Water droplet settling into electrostatic drum.
Usually, desalting process is skilled in the two key parts involving the separation of water free of crude oil in the gravitational tank and consequent stable emulsion separation in the electrostatic tank. Also, in desalting part inlet, demulsifying agent is mixed by oil to reduce oil and water emulsion interfacial tension. After that, fresh water is mixed by crude oil via a mixing element to dilute brine. The formed emulsion is entered the gravitational tank and water-free is divided.

Prior to electrostatic desalter, the crude oil is heated to decrease surface tension and viscosity to increase separation and mixing process. Subsequently, oil is pumped to desalter using charge pumps. In mentioned stage, dilution and emulsifier water is combined by crude oil. The mixture of water/oil is consistently emulsified in emulsifying part. The emulsification part is vital for contact among salty water in wash water and oil. After that produced emulsion is fed to desalter and it divorces into two phases with the alternating current field. Polarization of droplets of water attracts them of emulsion phase. The crude oil greeneries desalter part from top beside by small droplets. Fig. 2 shows the scheme of desalting process. In current investigation, the electrical mixing technique is established as an additional mixing valve. The main benefit of the mentioned method is reduction of necessary dilution water because of high mixing efficacy.

**Fig. 2.** The oil desalting unit schematic.

### 3. Mathematical modeling

Population balance simulation is the operational instrument to model of dispersed phases. Population balance has been used in the many sciences and furthermore in the chemical engineering field to simulate multi-phase phenome-nalike emulsions formation [13-15], polymerization [15], liquid/liquid extraction [16] and crystallization [17]. The population balance equation (PBE) is following as:
\[
\frac{\partial f (r, x, t)}{\partial t} + \nabla_x \cdot (v_x f (r, x, t)) + \nabla_x \cdot (v_s f (r, x, t)) = S_f (r, x, t)
\]

To solve PBE, two coordinates are defined as external and internal coordinates. The both coordinate systems describe the phase features and position of droplets, respectively. The volume of droplets in emulsion part is selected by way of the internal coordinate. The PBE is extended as:

\[
u \frac{\partial n(v, z)}{\partial z} = -g(v)n(v, z) + \frac{1}{2} \int_{w=0}^{v} \beta(v, w)n(w, z)n(v - w, z) \, dw + \int_{w= -\infty}^{\infty} m(w)f(v, w)g(w)n(w, z) \, dw - n(v, z) \int_{w=0}^{\infty} \beta(v, w)n(w, z) \, dw
\]

On the right side of the PBE, the first term characterizes the droplets breakage because of electrostatic forces. The second term and the third term characterize the droplets birth because of smaller droplets amalgamation and larger droplet breakage. Lastly, last term shows desired droplet death.

### 3.1. Mixing valve modeling

As mentioned previously, large droplets have more affinity to disintegrate. The initial stage is modeling mixing of crude oil and fresh water via mixing valve. Mitrea and coworkers [11, 18] presented a sensible breakage frequency to predict size distribution of droplet according to pressure drop term [12, 17]:

\[
g(d) = \begin{cases} 
K \frac{63.927}{W_{e\text{crit}}^{1/5}} \sqrt{\xi} C_{a\text{crit}}^{2.2} \left( \frac{d}{2\lambda} \right)^{3/2} & \text{if } Ca > Ca_{\text{crit}} \\
0 & \text{if } Ca \leq Ca_{\text{crit}}
\end{cases}
\]

\[
\xi = \frac{\Delta P}{t_{\text{res}} \rho}
\]

\[
W_{e\text{crit}} = \frac{8.2 \rho (\xi d_{\text{max}})^{2/3} d_{\text{max}}}{2 \sigma}
\]

In Eq. 4, \( t_{\text{res}} \) and \( \Delta P \) are the mixing valve residence time and pressure drop, respectively. The capillary number is defined as ratio of viscous force to interfacial tension [16]:

\[
Ca = \frac{\mu d \sqrt{\xi}}{2 \sigma}
\]

The empirical Gaussian equation is applied to predict the droplet breakage function [19]:

\[
f (d, d_0) = \frac{2.4}{d_0^3} \exp \left( -4.5 \left( \frac{2d^3 - d_0^3}{d_0^6} \right) \right)
\]

where \( d_0 \) and \( d \) are to initial diameter and final diameter of droplet, respectively. It is distinguished in the turbulent flow, both turbulent flow and Brownian motion effect collision rate between droplets. Therefore, the following equation are presented [20]:

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3.2. Electric mixing modeling

The main purpose of desalting in the refinery is to avoid the harms mentioned above. A conventional crude oil desalting plant involves of electrostatic drum, co-alescer tank and separator which are associated in series method. The water droplets are separated and settled of crude oil in co-alescer tank. After that, fresh water is mixed by crude oil to dilute brine and after that decrease concentration of salt. The ready emulsion is fed to electrostatic drum and brine is separated of oil. Between various desalination technique, usual technique is electric mixing which apply electric field. Direct current alternating current, dual frequency, electro-dynamic, modulated dual polarity and dual polarity are various usual technique in electrostatic desalting. This skill is usually investigated for the aqueous phase dispersed separation in the dielectric oil phase by a meaningfully lower dielectric constant compared to the dispersed one. Several designs have been presented, by most by means of alternating current electric fields with mains frequency. The other benefit of electric mixing technique is usage of chemical demulsifiers can adapt interfacial features of water/oil, consequently allowing water droplets to coalesce more easily in larger droplets. But, extra problems are encountered in elimination of demulsifiers of both oil and aqueous phases.

In new process, a mixing valve is substituted by the electrical field higher more than serious field to disperse the dilution water in crude oil [19, 21]. At high voltage, large drops break down in smaller drops and they are more stable. Because of the high electric field strength and breaking of droplets, fresh water is mixed by crude oil to dilute brine and decrease concentration of salt into the satisfactory level:

\[ E_c = 0.64 \left( \frac{\lambda}{2 \varepsilon_1 \varepsilon_0 r} \right)^{0.5} \]  

To complete electric mixing modeling, electrostatic desalter drum is modeled, too. Presented model is divided in both main parts, the first part investigated the presence electrical field and second part considers absence of the field. Subsequently, simplified form of PBE is as following form:

\[ \frac{\partial n(v, z)}{\partial z} + \frac{1}{2} \int_{v=0}^{v} \beta(v, v-w)n(v, z)n(v-w, z)dw - n(v, z) \int_{w=0}^{\infty} \beta(v, w)n(w, z)dw \]  

The \( u \) parameter in Eq. (12) is droplets relative velocity than the oil velocity [22]:
\[ u = u_e - \frac{2(\rho_d - \rho_c)gd^2}{9\mu_c} \]  
\[ \beta(d_i,d_j) = K \pi(d_i + d_j)V_i^{(0)}e_{ij} \]  
\[ V_i^{(0)} = \frac{(\mu + 1)|\rho_i - \rho_i|d_i^2(1 - \delta^2)g}{6(3\mu + 2)\mu_c} \]

Empirical correlations for aggregation efficacy without and with electric field are recommended in the literature [23, 23]:

\[ e_{ij} = 0.45 \left( \frac{2\delta \Delta \rho(1 - \delta)gd_i}{3\varepsilon(1 + \delta)E^2} \right)^{-0.55} \]

\[ e_{ij} = 0.3\delta^{1/2} + \frac{1}{2}B_i\delta^6 \]

### 3.3. Numerical solution of PBE

Equation (12) is the integro-partial-differential equation and its analytical solution is not available and analytical solution of population balance equation is promising for special cases. Then, numerical solution is used for most PBE. Many numerical methods have been suggested to solve PBE, like class method (CM), method of moments or quadrature method of moments and Monte Carlo method. Amongst various presented methods for the solution of population balance equation, the method of moment is one of powerful approach by unique benefits methods for solving population balance equation that is containing particle formation, coagulation and growth. This method can be reduced computational run-time than discrete population balance methods especially when PB is couple by computational fluid dynamics [24]. The key advantage of method of moment is that it gives the size distribution directly and it is more over willingly applicable when coagulation happens in system occurs and this technique can be determining the evolution of lower order. The quadrature method of moments was suggested for evolution of the order moments and solving PBE including pure growth with high accuracy and low computational cost. The quadrature method of moments calculates the population moments rather than its size subsequently; it is independent of minimum and maximum particle sizes. Although quadrature method of moments has some disadvantage such as destroying the shape of distribution [20-26]. Monte Carlo method uses probabilistic tools to sample a finite subset of a system. This method does not use particle trajectories. A well-known example of this method is the simulation of the Brownian movement by stochastic processes [14-17]. In sectional method or class method in first step particles are collected in bins or size classes. After that population balances are written for each size class that it leads to reducing the number of equations. Consequently, PBE is transferred into a linear differential system by discretizing the range of variation of the variable [26]. In present study, class method is applied to solve PBE. Also, \( n(v,z) \) is discretized in various classes. Where \( N_i(z) \) is droplets number in the \( i \)th class that their volume is among \( v_i \) and \( v_{i+1} \):
\[ N_i(z) = \int_{v_i}^{v_{i+1}} n(v, z) \, dv \]  

(18)

The PBE discretization using CM is used which converts the integrals to series as follows:

\[ \frac{dN_i(z)}{dz} = -g_i N_i + \sum_{j,k}^{i} n_{j,k} N_j N_k + \sum_{k=1}^{M} n_{i,k} g_k N_k - N_i \sum_{k=1}^{M} \beta_{i,k} N_k \]  

(19)

where

\[ n_{i,k} = \int_{x_i}^{x_{i+1}} \frac{1}{x_{i+1} - x_i} \, \left( \frac{x_{i+1} - v}{x_{i+1} - x_i} \right) \, mf(v, x_i) \, dv + \int_{x_i}^{x_{i+1}} \frac{1}{x_{i+1} - x_i} \, mf(v, x_{i+1}) \, dv \]  

(20)

\[ \eta = \begin{cases} \frac{x_{i+1} - v}{x_{i+1} - x_i} & x_i \leq v \leq x_{i+1} \\ \frac{v - x_{i-1}}{x_i - x_{i-1}} & x_{i-1} \leq v \leq x_i \end{cases} \]  

(21)

A number of discretized PBs or classes method have been suggested for modelling of aggregation, growth, nucleation and breakage. Now we consider the method suggested with Hounslow et al. [16]. As already mentioned, by using this method the internal coordinate is discretized, and thus in length-based expressions terms, it becomes \( L_{i+1} = L_i 2^{1/3} \). In the original formulation the discretization was fixed and the model was proposed only for molecular growth and aggregation. The aggregation among a particle in \((i-1)^{th}\) and in first to \((i-2)^{th}\) interval produces a new particle in \(i^{th}\) interval. Aggregation among two particles in \((i-1)^{th}\) interval consequences in the formation of a particle in \(i^{th}\) interval. The death phenomenon happens to a particle in the \(i^{th}\) interval must it aggregate by a particle of sufficient size for the resultant aggregate to be larger than the upper size limit of the \(i^{th}\) interval. If a particle in the \(i^{th}\) interval aggregates by a particle from that or a higher interval, a death happens in the \(i^{th}\) interval. The main advantage of this method stands in the possibility of defining the particle size distribution only by tracking a few lower-order moments. However, the method is not suitable when modelling size-dependent molecular growth, and size-dependent aggregation and breakage.

3.4. Measurement uncertainty

The measurement uncertainty has important effects on results assessment. The measurement device, Karl Fischer Titrator, indicates less than 0.5% of standard deviation by range of 1-11% of concentrations of water. Consequently, measurement devices uncertainties are insignificant. But, a human experimental error maybe affects the obtained results. Even if tests are done in same conditions, measurement of separation speed and concentrations of water can indicate minor changes. According to repeated tests results, experimental test error can be less than \(\pm 11\%\). While experimenting a range of challenges emerged. Electrophoretic influences, meaning horizontal displacement of single drops, happened particularly when contaminated particles and space charges accumulated in cell and Perspex cell static charging was encouraged. Subsequently needles are grounded, proper removal of injection expedient from the inter-electrode space is crucial to avoid an irritation of electric field. Even very small water drops sink
rather fast in dodecane, entailing a very short time interval in coalescence needs to happen. Consequently, reproducibility of the experiment demands for correctness in initial positioning of the needle tips and drop sizes.

4. Results and Discussion

To improve the perfect and complete model as a reference to predict the PSD of droplet via crude oil desalting, 111 droplet classes were investigated in 1-5000 μm range. To show an accuracy of investigated model, predicted efficiencies of dehydration are compared by the experimental data from the National Iranian South Oil Company. The investigated industrial unit characterizations, comparison among the modeling results and experimental data are given in Table 2. The results indicate the predicted dehydration and the desalting efficiencies are in good arrangement by the industrial experimental data.

Table 2. The considered industrial value and comparison among industrial data and modeling results.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate of crude oil</td>
<td>55000</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>51.4</td>
</tr>
<tr>
<td>Api</td>
<td>33.04</td>
</tr>
<tr>
<td>Water cut (%)</td>
<td>2.5</td>
</tr>
<tr>
<td>Fresh water temperature</td>
<td>105</td>
</tr>
<tr>
<td>Fresh water (%)</td>
<td>3</td>
</tr>
<tr>
<td>Desalting drum Diameter (m)</td>
<td>3.05</td>
</tr>
<tr>
<td>Length (m)</td>
<td>13.72</td>
</tr>
<tr>
<td>Electrodes length (cm)</td>
<td>30</td>
</tr>
<tr>
<td>Dehydration efficiency Modeling result</td>
<td>96.64</td>
</tr>
<tr>
<td></td>
<td>Industrial data</td>
</tr>
<tr>
<td>Water cut</td>
<td>0.094</td>
</tr>
<tr>
<td>Modeling result</td>
<td>0.1</td>
</tr>
<tr>
<td>Industrial data</td>
<td></td>
</tr>
</tbody>
</table>

The modeling results are given into two sections. The first step is focused on mixing technique and in second step; influence of mixing technique on the electrostatic desalter performance is studied. Fig.3 indicates the influence of the mixing valve pressure drop on water droplet PSD in crude oil. It is clear from the results which droplet PSD at the outflow of the valve is in the range of 60-500μm.
Increasing the pressure drop in the mixing valve leads to increased shear force on the emulsion, which increases the fresh water mixing process and the original water cut. Fig. 3 reveals that with increasing the pressure drop in the mixing valve, the large water droplets are broken down to smaller drops. It is distinguished that producing water droplets averaging around 59 µm leads to form a tight emulsion. Furthermore, natural surfactants in crude oil stabilize the emulsion. Fig. 4 indicates the influence of the strength of the electric field used in the mixing element on the water droplet PSD in the outflow of the crude oil.
When strength of electric field of any droplet surpasses the critical value, elongated droplets are broken in smaller drops \cite{26, 27}. The mentioned phenomenon can be applied as an actual emulsifying technique. It is indicated which, water droplets PSD of at the mixing stage outlet is narrow that provides well consequent separation in the electrostatic desalter. Usually, key difference between electric mixing technique and pressure drop according to mixing is introduced drops range in emulsification step. Commonly, the electric field strength has an important influence on the droplets PSD that leaving mixing section. The droplet PSD is in 100-500 μm range at the field strength of 80000 V/m, although it is in of 100-300 μm range and at 120000 V/m. Moreover, the PSD peak happens in 200 μm for all mixing pressure drops. The key benefit of electric mixing technique over conventional mixing method is breaking down of large water drops to the specific and preferred size range. So, by electric field as an emulsifying method, a secure range of droplets is produced that could have better consequent settlement. Usually, all water droplets larger compared than critical size are broken to procedure stable drops. It is distinguished, which if the electric field strength develops very high, peak at the mixing stage
outlet shifts to smaller droplet size. As discussed before, the desalting drum is separated in two parts. In the first section, the fluid is fed to the desalting drum and flows over the gravitational part in the electric field absence. In the downstream part, the fluid is distributed among flows and electrodes via an alternating current electric field. The rate of coalescence increases because of di-electrophoretic attraction force among polarized H₂O droplets. In conclusion, produced larger drops are established at the drum bottom section. Figures 5-6 indicate the influences of the pressure drop and electric mixing strength on the water droplets PSD at the electrostatic desalter outlet.

![Graph showing droplet number vs. diameter for different electric fields](image)

**Fig. 5.** Influence of electric field strength.

From the operational viewpoint, increasing both electric field strength and mixing valve pressure drop and can increase rate of droplet breakage leading to stable emulsion formation and a higher mixing efficacy. The comparison among both Figs. tells that with the electric field in place of the mixing valve, decreases water cutoff treated oil to a satisfactory level that leads to water cut lowest value at desalter outlet. Also, attained water cutoff of the treated crude oil according to several mixing techniques are given in Table 3.
Fig. 6. Pressure drop in mixing plans on PSD at desalter outlet.

<table>
<thead>
<tr>
<th>Mixing technique</th>
<th>Mixing Valve</th>
<th>Electrical Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure drop (kPa)</td>
<td>Water cut ($\times 10^{-2}$)</td>
<td>Field strength (V/m)</td>
</tr>
<tr>
<td>80</td>
<td>8.8</td>
<td>$1\times 10^6$</td>
</tr>
<tr>
<td>100</td>
<td>9.4</td>
<td>$1.1\times 10^6$</td>
</tr>
<tr>
<td>120</td>
<td>9.8</td>
<td>$1.2\times 10^6$</td>
</tr>
</tbody>
</table>

For identical volume of fresh water, it is indicated droplets can settle competently and number of droplets incoming upper part reduces that indicates the higher efficacy of electric mixing. The obtained results validate which increasing the mixing pressure drop from 0.98 to 1.1
atm, rises water cut in treated oil from $8.8 \times 10^{-2}$ to $9.8 \times 10^{-2}$. By increasing mixing valve pressure drop from 0.98 to 1.1 atm, small droplets number is increased in treated crude oil. The results indicated which there is the optimum value for electric field strength in mixing section which links to the minimum values of water cut in treated crude oil. Increasing the electric field strength in mixing stage of $1 \times 10^5$ to $1.1 \times 10^5$ V/m leads to increased numbers of sizedrops in emulsion. Also, it may be more over increased rate of collision and also, decreasing of water cut of 0.08 to 0.05%. But, increasing electric field strength from $1 \times 10^5$ to $1.1 \times 10^5$ V/m leads to increased water cut from 0.05 to 0.066% because of increasing number of small drops in emulsion. Subsequently, the collision small droplets rate is meaningfully less than large droplets, so, it is determined, which there is optimum strength of electric field to mix original fresh water and water cut.

Figs. 7 and 8 show droplet PSD through the electrical and gravitational parts of electrostatic drum according to the electric mixing technique. Subsequently, collision among rising and falling droplets happens at the low rate in the electric field nonappearance. The small droplets move with continuous phase flow and enter electrostatic part. The electric field risesthe rate of collision amongthe polarized droplets; subsequently, fine droplets are coalesced. The produced large droplets are entered and settled to gravitational part, consequently, the water content and the outlet crude oil salinity decrease considerably.

Fig. 7. Droplet PSD through the electrical and gravitational parts of electrostatic drum.
**Fig. 8.** Electrostatic sections of desalter drum considering electric mixing.

**Conclusion**

In this study, the electric mixing is suggested as an extremely effective substitute for conventional mixing valves to mix dilution crude oil and water in crude oil desalting. The suggested mixing plan, electrostatic desalting and drum mixing valve are modeled according to PBE. A comparison among the modeling results of plant data and conventional process indicated accuracy of developed model. According to the results, increasing the conventional mixing valve pressure drop from 0.9 to 1.3 bar leads to improved water cut at electrostatic desalter outlet from $8.8 \times 10^{-2}$ to $9.8 \times 10^{-2}\%$. The optimum amount of electric field strength is calculated to be 1.1 kV cm$^{-1}$ to achieve the lowest water cut in preserved crude oil (0.046%). The main benefit of electric mixing than to mechanical mixing by a mixing valve was found to be breakdown of large water droplets definitely to proper range and desired which leads to the highest efficiency. Comparison between the results of mixing valve and electric mixing proved the advantage of suggested technology precisely.
Nomenclature

\( B_i \) \hspace{1cm} Number of bond [-]
\( D \) \hspace{1cm} Diameter of droplet [cm]
\( E_o \) \hspace{1cm} Strength of electrical field [cm]
\( E_c \) \hspace{1cm} Electrical field [-]
\( E_f \) \hspace{1cm} Gradient of electric field [-]
\( F \) \hspace{1cm} Daughter drop size function [cm]
\( F_e \) \hspace{1cm} Electrostatic force [N]
\( G \) \hspace{1cm} Gravity [cm/s^2]
\( g \) \hspace{1cm} Breakage frequency [-]
\( H \) \hspace{1cm} Production of particles rate [-]
\( M \) \hspace{1cm} Fragments formed number [-]
\( n \) \hspace{1cm} Continuous number density [-]
\( N_{brown}, N_{turbulent} \) \hspace{1cm} Collisions number [-]
\( N_i \) \hspace{1cm} Discrete number density [-]
\( P \) \hspace{1cm} Pressure [kPa]
\( T \) \hspace{1cm} Temperature [°C]
\( U \) \hspace{1cm} Velocity [cm/s]
\( u_c \) \hspace{1cm} Velocity of continuous phase [cm/s]
\( v \) \hspace{1cm} Settling velocity [cm/s]
\( V_{ij} \) \hspace{1cm} Relative velocity [cm/s]
\( \chi \) \hspace{1cm} Center-to-center distance among drops [cm]
\( We \) \hspace{1cm} Weber number [-]

Greek letters

\( \sigma \) \hspace{1cm} Interfacial tension [N/m]
\( \lambda \) \hspace{1cm} Kolmogorov length scale [m]
\( \rho \) \hspace{1cm} Oil density [g/m^3]
\( \mu \) \hspace{1cm} Oil viscosity [g/cm.s]
\( \varepsilon_{oil} \) \hspace{1cm} Crude oil dielectric [farad/m]
\( \varepsilon_0 \) \hspace{1cm} Free space permittivity [-]
\( \beta \) \hspace{1cm} Coalescence frequency [-]
References


