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Effect of Temperature and Electric Field on Demulsification of Water-Oil Emulsion

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In this work, desalting and dehydrating of crud oil in water-in-oil emulsion type is investigated under non-uniform electrical field using direct current (DC) and the results are compared with the ones of available methods. The effect of time, temperature and voltage on separation efficiency is also considered. The results show that the inhomogeneous electrical field method can be the proper and suitable way to desalt and dehydrate the water-in-oil emulsions. In laboratory conditions of 8000 to 10000 volts of voltage at 50 ºC the separation efficiency of 96 % is achieved.

Key Words: Electrical field, Separation, Water-in-oil emulsion.

INTRODUCTION

From the industrial production point of view, the extracted crud oil from wells usually contains saltwater, especially when taking the final capacity of the oil well, which is increased in amount when approaching the depth of the wells. The continuous phase (oil) surrounds the dispersed phase (water droplets). This mixture is called water-in-oil emulsion. Most of crude oils contain sodium and magnesium chlorides, a small amount of sulfate, silica and ferro-oxides[1-5]. Even if they do not contain these compounds when extracting, during the transportation with tankers, these salts will enter the oils. Chlorides and sulfates are dissolved in emulsified water droplets. The amount of these salts is different. In the Middle East oils they are less than in the Egypt oils[5,6]. Since the salt deposits cause corrosion of installations, in almost every refinery the desalting process is done on the crude oil. The salts dissolved in the washing water and then in the separating tank water and oil separation. This separation is done either by adding demulsifiers or by producing an electrical field with high potential. The usage per cent of washing water and the operation temperature depend on the crude oil density.

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From an industrial and environmental point of view, separation of water-in-oil emulsion is of great importance. The desalting equipment is the main source of waste water in a refinery and a small problem of a part of it can break up the waste water circulation and cause problems for its evacuation[5-10].

Permeation and leakage of oil in drains is also a dangerous pollutant of the environment. These pollutants, which are in the form of emulsions, can pollute the mineral waters, rivers, lakes and total environment. The harmful kind of these emulsions can be found in oil leakage from the oil tanker ships to the seas, which needs quick purification of the water surface from this emulsion and separation of it. Thus in different industrial processes the break up of water-in-oil emulsion and separation of them is necessary. The quick performance and the high efficiency of this process is of great importance in continues emulsion productions (such as drains or extracted oils). Many efforts are made for the recognition of the economical and practical break up and separation processes. The emulsion must break up in order to desalt the oil and increase its purity. The basis of the desalting process is the dissolution of the oil salts in water. The difficulty of the problem is preparing an effective oil and water mixture, moistening the solid particles and separation of the washing water and oil[11].

There are different methods for the separation of water-in-oil emulsion. The main methods are: (a) Natural settling (Fig. 3), (b) Homogeneous electrical field or electrophoresis (un-insolated electrodes), (c) Non-uniform electrical field or dielectrophoresis (insolated electrodes), (d) The chemical method[12].

If the emulsion is unstable the separation of water-in-oil emulsions can be done by the natural settling method (without the presence of electrical field), however it is too slow and has low efficiency which makes it less practical and economical.

The coagulation and coalescence rate of the dispersed phase in an emulsion can be increased by using an electrical field. Thus the methods based on electric current are also under consideration. Different kinds of electric currents such as alternating currents (AC), pulsed alternating currents (PAC), direct currents (DC) and pulsed direct currents (PDC) affect the elecrtrocoagulation. The alternating currents (AC) are used since 1911. The direct current (DC) is used for desalting the crude oil when it contains a little percentage of water. In the homogeneous electrical field, both of the electrodes are put in to the separator vessel. If the water percentage in emulsion is high, a chain of water droplets forms which causes electrical conductivity in the emulsion and may cause a short circuiting and disable the electrical field[13-16].

The chemical method is used in many separation processes. However it is not consistent with the environment due to the chemical material usage. On the other hand it needs continues usage of these materials thus it is not an economical method. For example in the Neka Oil Export Terminals (Iran) the chemical method is used to specify the percentage of water in the oil cargo which lasts for about 1 h. It is necessary to make the awaiting cargo test minimum, which lessens the staying duration of the tanker and helps the optimum usage of the quay.

There are also other suitable methods such as gravity or centrifugal settling, filtering, heat treatment, membrane separation and combining methods. Combination of the electrical coagulants and the mechanical separation (such as the centrifugal force) or heating and adding chemical materials is one of the methods to increase the water droplets elecrtrocoagulation in the emulsion[14].

Each of these methods has advantages and disadvantages. For example the chemical demulsifiers (chloro compounds, toluene, hydrochlorate) can modify the water/oil interfacial properties thus allowing water droplets to coalesce more easily into larger droplets; however they have undesirable environment and economical effects.

The centrifugal method is effective for some emulsions, but it is not suitable for stable emulsions such as the one we consider in this paper and it is also has a high operating cost[14-17].

The heat treatment can reduce the oil viscosity; however such as the centrifuge method it is not an effective way when used alone.

As mentioned above, since the formation of water droplets chain is probable and it may lead to an electrical short circuiting between the electrodes, it is difficult to use the homogeneous electrical field (the un-insolated electrodes) to coagulate the particles in the emulsion with the water concentration of 20 % and over. This problem can be solved by using separate electrodes (inhomogeneous electrical fields). In this case we need a variable electrical field. Water-in-oil type emulsions are readily formed in the production of crud oil causing problems in different stages of production. For example corrosion of pipes, pumps and other are processing equipment. Besides, the deactivation of catalysts by water droplets is a consequence of the presence of water. Thus there are commercial reasons to remove the emulsified water from crud oil. In this paper the results of an experimental research on the separation of an artificial saltwater and oil emulsion by using the inhomogeneous electrical field method (the insolated electrodes) is inspected to remove the mentioned imperfections[15-17].

Water-in-oil emulsion breaks up theory in a non-uniform electrical field

The concept of variable electrical currents with separate electrodes was developed in 1981. Soon after, this method was the most common technology of the electrical coagulants. The inhomogeneous electrical field (the insolated electrodes) is more useful compared to the homogeneous electrical field when the amount of aqueous phase of the emulsion is high, because it prevents the short circuiting between the electrodes. When creating an inhomogeneous electrical field, electric charge will induce on the outer surface of the emulsion droplets and they will start to migrate toward the central electrode where the highest field intensity (voltage gradient) exists. During this process the droplets collide to each other and make bigger and heavier drops and ultimately they will settle by the gravity force. During the settling process the oil layer between the drops becomes thinner and thinner by the drag force and will be torn at last. Thus the oil which has greasy characteristics and has less specific gravity than water will be separated and floated. This process takes place in less than 10 min and the formation of two phases is completely observable in the vessel. Thus in the shortest possible time the floated oil can be separated from water. The volumetric amount of the separated saltwater is measured by a central glass cylinder which is scaled at the bottom[17].

Consider a glass vessel containing water-in-oil emulsion. This mixture is observable and controllable from outside of the vessel. Applying an inhomogeneous electrical field causes the induction of electric charge on the outer surface of the water droplets and makes the droplets migrate toward the center of the electrical field where the highest field intensity exists. The droplets collide to each other in their way and make bigger drops and settle at last by the gravity force due to the density difference and according to the Stokes law. During the settling process the oil layer between the drops becomes thinner by the drag force and will be torn ultimately which will cause the rupture of the drops. Thus the oil which has greasy characteristics and has less specific gravity than water will be separated from water and floated. This process happens in a short time and the formation of two phases is completely observable in the vessel. Thus in the shortest possible time the floated oil can be separated from water[17-20].

The two following points are so important in selecting the glass thickness as the insulator: (i) The glass should have the required thickness for the electric shocks. (ii) The glass should not be too thick, because it will waste excessive field intensity.

Because the field intensity should only affect the emulsion, not the glass insulator, the dielectric constant should be high according to eqn. 1:

$$\frac{E_c}{E_d} = \frac{\varepsilon_d}{\varepsilon_c} \quad (1)$$

The dielectrophoresis force (Fd_i) equation for a concentric cylindrical vessel is given by:

$$Fd_i = \frac{\pi d^3 \varepsilon_c (\sigma_d - \sigma_c) E^2}{2(\sigma_d + 2\sigma_c) R. \ln^2 (D_a / D_i)} \quad (2)$$

When the water-in-oil emulsion is placed in an inhomogeneous electrical field, electric charge will be induced on the outer surface of the water droplets (dispersed phase). One of the dielectrophoresis (the inhomogeneous electrical field) characteristics is that the drops, regardless of their charge, attract to an electrode where the highest field intensity exists (the metal electrode in center). The flux lines, as shown in Fig. 1, come together at the center which shows the highest electrical field at center and the maximum collision of the particles happen in this place (voltage gradient). As we move away from the center, the electrical field becomes weaker[21].

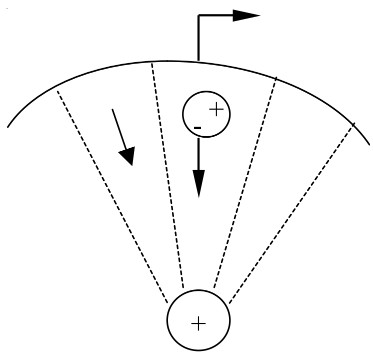

Fig. 1. Effect of non-uniform electrical field

Fig. 1 shows the inhomogeneous electrical field (dielectrophoresis) method. The highest electrical field is at the center due to the electrical flux configuration. The electrodes are separated in two different glass vessels[22].

EXPERIMENTAL

In this laboratory research, the artificial water-in-oil emulsion is made by using an ultrasonic mixer and by mixing water and oil with the volumetric ratio of 7 to 90, respectively. The separator consists of three concentric glass vessels as shown in Fig. 2. The central glass vessel which contains a sample of the emulsion is viewable and controllable from the outside and it is selected as the separating vessel. This apparatus can be imagined as three concentric glasses or cups. The central glass (the smaller one) contains the emulsion, the second glass contains the 30 % acid and the outer glass works as a heat exchanger. The emulsion containing vessel is 4 cm in diameter and 42 cm in height. The 30 % acid containing vessel is 8 cm in diameter and 38 cm in height and the cooling water vessel is 12 cm in diameter and 38 cm in height[14].

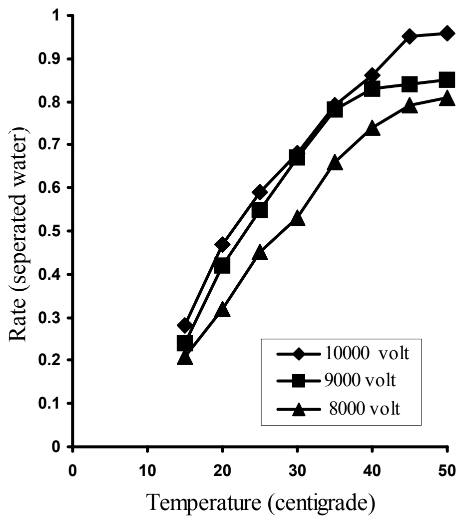

Fig. 2. Effect of temperature on the separation efficiency in different voltages in an inhomogeneous electrical field

In order to produce different voltages, a DC apparatus (direct current) is used. Under this inhomogeneous electrical field with direct current, the electrodes are put into separate glass vessels. The first metal electrode is in the central vessel (the emulsion containing vessel) and one of the ends of it is connected to a copper wire. In the adjacent vessel the diluted 30 % sulphuric acid is used as the second electrode and a copper wire is also put in it. The ends of the copper wire are connected to a generator and when the electricity is produced the inhomogeneous electrical field takes place. In the outer vessel water with different temperatures continuously flows to transfer heat to the emulsion. In order to compare the results the same experiment is done on a witness sample of the emulsion in another vessel without the presence of electrical field and by the natural settling. The voltage is transferred through two cupper wires. Since the resistant force of the glass (Ω) is so high, electricity does not pass through the electrolyte.

The effect of different conditions such as temperature, voltage and time on the dehydration of oil (as the separation efficiency) is also considered in this research. Eight different temperatures between 15 to 55 °C and three voltages of 8000, 9000 and 10000 volts have been selected. The frequency and time are constant in each experiment and are 50 hertz and 10 min, respectively. The separation efficiency is calculated by measuring the volumetric amount of collected saltwater in the scaled central cylinder. The washing water usage per cent and the operation temperature depend on the oil density. Table-1 shows the role of oil API in the percentage of washing water usage and the operation temperature.

TABLE-1

API	Volumetric percent of washing water usage	Temperature (ºC)
API > 40	3-4	115-125
30 < API < 40	4-7	125-135
API < 30	7-10	140-150

RESULTS AND DISCUSSION

When the continuous phase is oil, its permittivity is so less than the water droplets or the dispersed phase. In this case the continuous phase conductivity is low and it plays the role of an insulator between the electrodes.

According to the obtained results it is proved that the electrical coagulants are effective in water-in-oil emulsion separation and the insolated and separated electrodes for breaking up the water-in-oil emulsion (the varying electrical field) not only prevent the short circuiting but also increase the separation efficiency due to the geometry of the separating vessel in this method (Fig. 1). To summarize we can say the main aim of coagulation and coalescence and making new equipments and apparatus is to minimum the separation time of the water-in-oil emulsions and to have a high efficiency. To achieve this goal fundamental understanding of the electrical fields, electrodes, dispersed phase and the mechanism is necessary. Besides the oil and petroleum industries, this technology has potential applications in edible oil industries such as palm oil, sunflower oil and vegetable oil processing. Thus a better understanding of the fundamentals of the coalescence will enable a better design of the geometry of the electrodes, of the flow field with respect to the electric fields, the type of dispersion and the type of applied electrical field[14-20].

Necessity of separation in presence of the electrical field: Fig. 3 shows the separation process with and without the presence of the electrical field. A witness sample in a separator without the effect of electrical field is used in this experiment and separation is performed by the natural settling only. Comparing the first curve (the witness sample) of Fig. 3 with the others (with the presence of the electrical field) clearly shows that the separation process does not perform by the natural settling (without the presence of electrical field). This shows the necessity of an non-uniform electrical field for the quick break up of the water-in-oil emulsion.

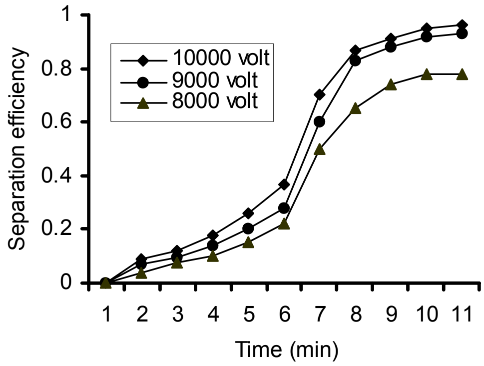

Fig. 3. Effect of voltage on the separation efficiency at the optimum temperature of 50 ºC and the frequency of 50 Hz

Effect of temperature on the separation efficiency (the optimum temperature): The effect of temperature on the separation efficiency is considerable. Fig. 2 and 3 display the effect of temperature on the separation efficiency in different voltages under an inhomogeneous electrical field with direct current. Considering Fig. 3 it is obvious that in 50 ºC of temperature and over the separation process performs better. This happens because the particles motions increase while temperature increases, thus the number of collisions increase in a specific time section and the settling and separation efficiency increase consequently. In all these figures the experiment duration is constant and equals to 10 min for all temperatures. Over the 50 ºC of temperature the separation efficiency remains almost constant; thus the best temperature for the separation process[16,23] is 50 ºC.

Effect of voltage on separation efficiency (the optimum voltage): Fig. 3 displays the effect of voltage on the separation efficiency in an inhomogeneous electrical field with direct current. Considering this figure it is obvious that up to 10000 volts of voltage in all of experiment durations the electrical field increases while the voltage increases. As mentioned above in theory section, the highest electrical field in this method exists at the center of the vessel, where the metal electrode is. This happens because of the voltage gradient and the more accumulation of electrical flux at the center which have had a great influence on the separation efficiency. The separation efficiency difference between the 8000 and 10000 volts of voltage is negligible. This little difference is observable in the first minutes of separation and in the last minutes, as shown in Fig. 3, the separation efficiency is almost the same. Thus the best field intensity happens in the 10th minute of separation and between 8000 to 10000 volts of voltage[17-19,22-25].

Fig. 3 shows the effect of voltage on the separation efficiency at the optimum temperature of 50 ºC and the frequency of 50 Hz in an non-uniform electric field with direct current[11].

Conclusion

(i) By using inhomogeneous electrical field in water-in-oil separation process the risk of short circuiting is weakened compared to homogeneous electrical field. (ii) In the inhomogeneous electrical field method the voltage (voltage gradient) and temperature are the most important parameters in emulsion separation. (iii) The separation efficiency increases by increasing voltage and temperature up to a limit. (iv) Compared to the natural settling method, the separation duration in this method is much less and the efficiency is much more. (v) Compared to the chemical method, since there is no chemical material usage in this method it is in more consistency with the environment and it is also more economical. (vi) In this research, it is shown that the best result for the separation under the inhomogeneous electrical field happens at the 50 Hz of frequency, 50 ºC of temperature and 10000 volts of voltage and after separating saltwater from oil an efficiency of 99 volumetric percent is achievable.

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