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Treatment of Fluid in Fluid Emulsion by External Electric Field

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Separation of fluid in fluid emulsions has been found to be induced by applying a non-uniform electric field. Electric current leads to move oil particles in emulsion contact each other and also create bigger oil drops by induction of negative charge, then the oil moves upward due to density difference and can be measured. Based on these experiments, about 92 % benzene deemulsify from the emulsion in lower than 30 s, which indicates that the mutual contact of oil droplets through thin water layers is necessary for the rapid deemulsification. All this evidence strongly suggests that the applied electric field causes the rearrangement of surface charges on oil droplets, which results in the reduction of the height of an energy barrier for the coalescence of the droplets. In the present paper, benzene is used as disperse phase and water is used as continuous phase.

Key Words: Oil-in-water emulsion, Demulsification, Electric field.

INTRODUCTION

Although emulsion systems have been widely used in many industrial fields, the formation of an emulsion is not always desirable in chemical industries. There are two forms of emulsions: oil-in-water (o/w) and water-in-oil (w/o). The demulsification of o/w emulsions can be accelerated by several chemical and physical methods. Chemical methods include the use of demulsifiers[1-5] or acids or bases[6-8]. Although chemicals used for the demulsification increase the coalescence rate of oil droplets by affecting the interfacial properties of oil droplets, they inevitably contaminate the purification systems. The chemical methods are, therefore, not the preferable choice. Physical methods include the use of heat[9,10], electric field[11-14], filtration and membrane of fabrics application[15-22]. These physical methods are considered to increase the contact frequency of oil droplets. The demulsification of w/o emulsions under high electric field has been extensively studied[23], since the electrostatic separation of water from crude oil is one of key technologies in the petroleum industry. However, the electrical demulsification of o/w emulsions has not been much studied.

In the present paper, it is shown that o/w (benzene in water) emulsions may be separated into water and oil by applying an electric field.

EXPERIMENTAL

The used materials in this experiment are as following: benzene, distilled water, sulfuric acid with 30 % volume, sodium dodecyl sulfate (SDS, ionic surfactant), as an emulsifier and instruments like magnetic stirrer, electric current source, electrode and glass dishes can be used as well.

Preparation of emulsion: Emulsion is made by a magnetic stirrer, a super facial actuator material, sodium dodecyl sulfate (SDS) was used. To make emulsion with different percents, we should take enough oil (benzene) and add 1-2 drops of emulsifier into the oil that is stabilizer. The total amount of emulsifier in whole emulsion is about 2-4 ppm, then extend the emulsion volume with distilled water to 250 mL, then transfer it into the glass dish which is prepared for blending after 25 times shaking. It is blended by a magnetic mixer during 15 min. After the mixture, let the combination separate until the amount of oil that deemulsifies itself from the emulsion.

Plant specification: The deemulsification plant is made of three involutes glass cases. The central glass case includes emulsion sample and can be seen by outside. Its diameter is 40 mm, thickness 1.6 mm and height 330 mm; this case is for deemulsifying the emulsion. The second cylinder includes 30 % sulphuric acid as an electrolyte solution, the diameter is 70 mm and the height is 320 mm. The biggest case relates to hot bath in order to control the temperature parameter. The experiment is done on a still emulsion and in atmosphere pressure to create different voltages in an auto-trans plant, having capability of creating AC and DC currents. All the currents were experimented by two steel electrodes, placing in two separate glass cases.

RESULTS AND DISCUSSION

The o/w emulsion was made by benzene oil. The oil content in water was 4 % volume. To prepare this emulsion, we mixed 20 mL desired oil with water, kept it for 0.5 h. There was no change in volume and then use emulsion for experiment. Immediately after putting emulsion in electrical field, the deemulsification took place. Of course the demulsification does not take place in vicinity of an electrode; rather the demulsification simultaneously takes place over the entire space between two electrodes. The result of olive oil and toluene mixture behaves similar to the results of benzene. The demulsification completes in 30 s and the transparent oil layer accumulates above. By using DC current for separation, it can seen the charge induction over the oil particles well. During the experiments it was also found that benzene in water emulsion, using 3 ppm emulsifier is one of the best o/w emulsion systems to show severe influence of outside electric field in each lab.

It is found that the emulsions which was separated under the applied electric field, has three following conditions:

(1) The emulsion should be o/w, not w/o. (2) The emulsion particles have close contacts. (3) The emulsions particle separated due to the electrostatic force resulting from particle surface charges. By increasing the voltage, the separation speed raises. But using voltages higher than 500 V leads water and electrodes to electrolysis severely as a result, in progress of separation, the emulsion layers volume among electrodes and separation speed decrease.

DC Field performs better than AC current in dielectrophoresis due to connecting and disconnecting the electrical current. As can be seen in figures, in separating by DC current, the lower voltage was used to obtain the same per cent of separating AC current. It shows the superiority of DC over AC.

As we can see in Figs. 1-2, by increasing voltage, the demulsification efficiency in an electric non-uniform field by AC and DC increases. The biggest electric field in this way is placed in middle, where a metal electrode places in emulsion. This is in center because of voltage gradient and more accumulation of electric charge that has so much effect on the demulsification efficiency.

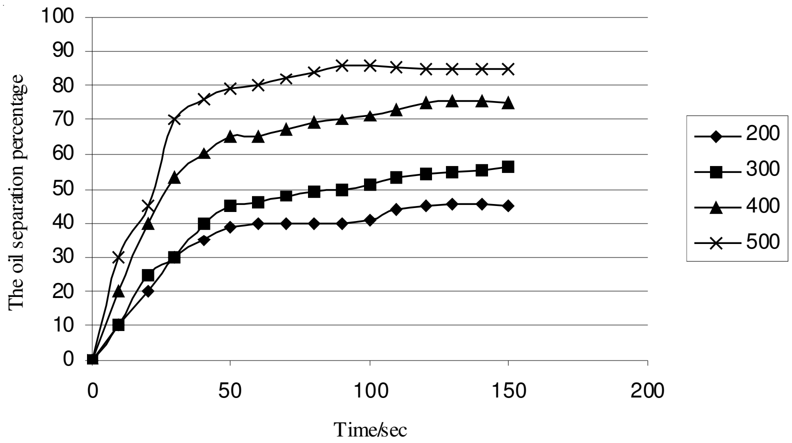

Fig. 1. Effect of AC field on the demulsification of the benzene/water emulsion

The demulsification of o/w emulsions composed of closely packed charged oil droplets under electric fields indicates that the electric field perturbs the stability of the emulsions through electrostatic interactions. According to the DLVO theory, the stability of charged colloidal or emulsion particles in an ionic solution is determined by the balance of two forces acting between them[24]. They are attractive van der Waals force and electrostatic force which is usually repulsive. The latter force is further divided into Maxwell's electrostatic stress and osmotic pressure[25,26] arising from the difference of the ionic concentration from the bulk solution and is determined by the distribution of electrostatic potential between the droplets. Two emulsion particles do not coalesce if the total force is repulsive. Hogg *et al.*[27], derived the electrostatic potential energy for two charged particles in an ionic solution (U_E) which is given by

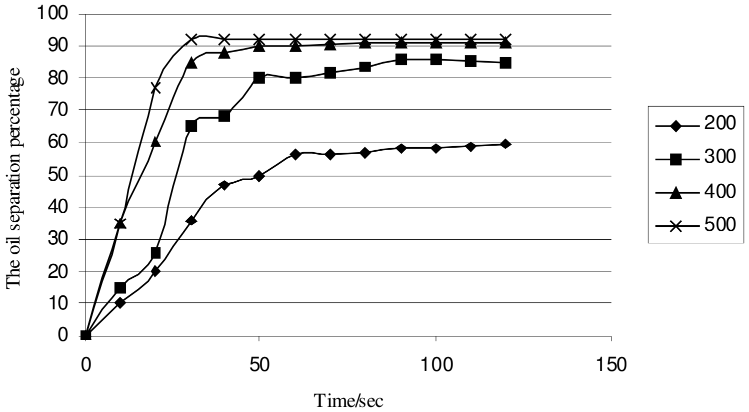

Fig. 2. Effect of DC field on the demulsification of the benzene/water emulsion

$$U_E = \frac{\pi\varepsilon_1 a_1 a_2}{a_1 + a_2}(\Phi_1 + \Phi_2)^2 \log(1 + e^{-kH}) - \frac{\pi\varepsilon_1 a_1 a_2}{a_1 + a_2}(\Phi_1 - \Phi_2)^2 \log\left(\frac{1}{1 - e^{-kH}}\right) \quad (1)$$

here a_i and Φ_i are the radius and the surface potential of particle i, ε_l the dielectric constant of water, H the shortest distance between the surfaces of two particles and κ is the Debye-Hückel reciprocal length given by

$$\kappa = \sqrt{\frac{2\pi z^2 e^2}{\varepsilon_1 kT}} \quad (2)$$

where n and z are the number density and the valence of ions in solution, e is the electronic charge, k is Boltzmann's constant and T is the absolute temperature. Eqn. 1 is valid only for values of Φ_i less than 50 mV, since the equation was derived by using the approximation of $e^{-x} \approx 1 - x + x^2/2$. It is noted that the first and the second terms in the right hand of eqn. 1 are always positive and negative, respectively, since $0 < e^{-\kappa H} < 1$. The first and the second terms therefore contribute to the stabilization and destabilization of emulsion, respectively.

Under no applied field, the surface potentials of both the two particles are given by[28]

$$\Phi_0 = \frac{\sigma_0}{\sqrt{\frac{2\varepsilon n z^2 e^2}{kT}}} \quad (3)$$

The value of Φ_0 is usually less than 100 mV. Substitution of eqn. 3 into eqn. 1 gives

$$U_E = 2\pi\varepsilon_1 a \Phi_0^2 \log(1 + e^{-kH}) \quad (4)$$

The electrostatic energy given by eqn. 4 monotonously increases with decreasing H, which indicates that the electrostatic energy prevents the coalescence of the emulsion particles.

An external electric field is possible to change the electrostatic energy to result in the coalescence of two emulsion droplets. The thickness of water preventing the coalescence of the droplets, H, is the order of $1/\kappa \approx 10$ nm. The external field does not perturb the distribution of surface charges, if the charges are immobilized on the surface of the droplets. The surface potential is then simply given as a sum of the applied external potential and Φ_0. Taking the standard of the potential at the middle of the adjacent droplets, the electrostatic potentials of the adjacent surfaces are given by[28]

$$\Phi_1 = \Phi_0 - \frac{E_0H}{2} \approx \Phi_0, \qquad \Phi_2 = \Phi_0 + \frac{E_0H}{2} \approx \Phi_0 \tag{5}$$

Since the value of $E_0H/2$ is generally much smaller than that of Φ_0. The external field therefore gives no effect on the stability of the emulsion droplets.

Now, let us consider what happens if charges on emulsion droplets moves freely like conduction electrons in metal. The droplets are then regarded as two metallic spheres immersed in an ionic solution. Application of an external electric field to a metal sphere causes the induction of surface charges that compensate the non-homogeneity of the external potential on the surface. The surface electrostatic potential under a homogeneous parallel electric field E_0 is given by E_{0x}, where x is the location of the center of the sphere. Assuming the radii of the droplets are the same, the electrostatic potentials of the adjacent surfaces are given by[28]

$$\Phi_1 = \Phi_0 - E_0a, \qquad \Phi_2 = \Phi_0 + E_0a \tag{7}$$

Substitution of eqn. 6 into eqn. 1 gives

$$U_E = 2\pi\varepsilon_1 a\Phi_0{}^2 \log(1 + e^{-kH}) - 2\pi\varepsilon_1 a(E_0a)^2 \log(\frac{1}{1 - e^{-kH}}) \tag{8}$$

The first and the second terms of the above equation contribute to the stabilization and destabilization of emulsion, respectively. The value of the first term decreases with decreasing Φ_0, so that the decrease of sodium dodecylsulfate concentration or the increase of ionic concentration in water accelerates the electric field-induced deemulsification. The absolute value of the second term increases with increasing E_0, so that the increase of the external electric field accelerates the deemulsification. The second term rapidly decreases with increasing separation distance H between adjacent emulsion particles, so that the electric field-induced deemulsification is operative only for dense o/w emulsions. Emulsions stabilized with nonionic polymer surfactants, are not demulsified by the external field, since they are stabilized not by electrostatic interactions but by strict effects of polymer molecules adsorbed on the surface of emulsion droplets.

For estimating the effect of external electric field on the stability of emulsions, we have regarded charged o/w emulsion droplets as metal particles with approximately infinite number of positive and negative charges. This may be an oversimplified assumption, since an emulsion droplet has infinite number of charged particles only on the surface. However, as long as the charged particles on the surface are mobile, the essence of the discussion is applicable to real o/w emulsion systems. A detailed theory for the electrostatic demulsification of o/w emulsion will be given in a subsequent paper.

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