Investigation of the influence of low frequency electric fields on model water-in-oil emulsions

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Abstract. The article describes the mechanisms of coagulation and coalescence of emulsion droplets in electric fields, and also defines the frequency ranges at which coagulation and coalescence of emulsion droplets occurs, and the establishment times of these processes. The experiments revealed the tendency to increase the intensity of the studied processes with increasing field strength and salinity of the aqueous phase.

1. Introduction

One of the main tasks of oil production is the destruction of water-in-oil emulsions. Water-in-oil emulsions are basically a heterogeneous system consisting of micron drops of water dispersed in oil. Each drop is surrounded by high molecular weight oil components, which prevents the coalescence of water droplets. The emulsion destruction mechanism is based on two processes: coagulation and coalescence of droplets.

Stimulation of these processes is possible using low-frequency electric fields. The choice of the frequency of the electric field depends on the physicochemical properties of the emulsion. In the low-frequency range for values from 1 to 100 kHz, the formation of chains, elongated mainly along the direction of electric field lines, is observed [1-3]. Adamiak [4] investigated the deformation of two perfectly conducting, uniform size drops in a uniform electric field numerically. The attraction of individual water droplets in an electric field and the formation of coagulation chains are mainly due to the action of electrophoretic forces on the droplets [5], determined by the formula.

\[ F_{DEP} = 2\pi\varepsilon_{1} R^{3} \left( \frac{\varepsilon_{2} - \varepsilon_{1}}{\varepsilon_{2} + 2\varepsilon_{1}} \right) \nabla E_{0}^{2}, \]

Where, \( \varepsilon_{1} \) is the dielectric constant of the medium, \( \varepsilon_{2} \) is the dielectric constant of the drop, \( R \) is the radius of the drop, \( E_{0} \) is the strength of the external electric field.

The rapprochement of water droplets under the action of electrophoretic forces occurs until the energy barrier of the repulsive forces is overcome, after which the coalescence of the droplets occurs. The energy barrier of repulsive forces depends on the strength properties of the droplet shell. Consequently, the patterns of coagulation and coalescence will depend on the physicochemical properties of the phases of the emulsion and dispersion, as well as the frequency and field strength.

JD McLean et al [6] studied the effect of a low-frequency electric field on multiple and individual drops of model emulsions of various concentrations and with different phases of water salinity, which affected the dielectric constant of the drop. To produce a model emulsion, asphaltenes (for values from 1 to 8 % of the emulsion volume) are dissolved in toluene within two hours, heptane is...
added to the resulting solution in equal proportions to toluene and mixed for 2 hours in a mixer at a speed of rotation 500 rpm, water with different NaCl content (0 mg/l; 10 mg/l; 20 mg/l) is added to the resulting solution in a volume of 20% of the volume of the emulsion and mixed for 20 minutes in a mixer at a speed of rotation 3000 rpm.

2. Material and methods
To visualize the behavior of emulsion droplets in electric fields, a laboratory bench was developed. Figure 1 shows a schematic diagram of laboratory setup. The electric field is set by the generator AG 1021 (T&C Power Conversion) with a frequency range for values from 0.1 to 15 MHz and a variable power of up to 300 W. An electromagnetic field is supplied from the generator via an RG6 radio frequency cable to two parallel copper conductors. To control the applied voltage, an oscilloscope is connected to the line.

![Figure 1. Scheme of a laboratory bench for the influence of an electric field on emulsions.](image)

3. Results
The research results showed that in emulsions with distilled water (NaCl 0 mg/L), coagulation chains in an electric field are not observed. For samples of emulsions with salt water (sample No. 1 - NaCl 10 mg/L; sample No. 2 - NaCl 20 mg/L), droplet aggregates in the form of chains extended mainly along the direction of electric field lines are formed. Figure 2 presents the frames before and after electrical exposure. The exposure parameters (field frequency, field strength, exposure time) were selected individually for each emulsion sample.

![Figure 2. Photos of the structure of the emulsion (water - 20%, NaCl - 10 mg/l, drop radius 1 - 60μm) before (left) and after (right) influence of the electric field (f = 70 kHz, E = 87 kV/m, t = 7 s).](image)
Figure 3 and 4 present the results of a study of the dynamics of the formation of coagulation chains for emulsion samples No. 1 and No. 2, depending on concentration of water in the emulsions and the electric field strength. Emulsion No. 1 contains water with a higher salinity than emulsion No. 2.

**Figure 3.** Dependence of the time of formation of coagulation chains on the concentration of water in the emulsion (◊ - sample No. 1, • - sample No. 2).

**Figure 4.** Dependence of the time of formation of coagulation chains on the power of the electromagnetic field (◊ - sample No. 1, • - sample No. 2).

The graphs show that for a sample with high salinity of water, the intensity of chain formation increases. With increasing water concentration up to 30%, therefore, the number of drops, the time of formation of chains decrease. Above 30%, a slight increase in time is observed. With increasing field strength, the time difference between the samples under study decreases.
Next, the mechanism of coagulation and coalescence of individual drops was investigated. A discharged emulsion is fed into the cell and two drops of different diameters are fixed in the center between two electrodes at a distance for values from 10 to 30 microns from each other. Then, a voltage with a frequency of 100 kHz and amplitude from the range for values from 50 to 120 V, starting from the minimum amplitude, is supplied to the electrodes. The amplitude values are fixed when the attraction and coalescence of droplets occurs. Figure 5 presents fragments from the video. Exposure time was 1s. The radius of the big drop is 57 μm, the radius of a small drop is 17 μm.

![Figure 5. The effect of an electric field on emulsion droplets.](image)

**Conclusions**

In the absence of drops in the center of the cell between two electrodes, the electric field is uniform, i.e. field strength is constant. The appearance of a droplet violates the uniformity of the field around the droplet, and a gradient of electric field strength arises at a certain distance. Drops of a smaller radius located in the region of heterogeneity are attracted to this drop. There are 3 stages in the observed processes. When the electric field reaches 112 kV/m, a drop with a smaller radius begins to move to a large drop. When the electric field reaches 117 kV/m, the system of two drops begins to line up along the field, but the drops do not coalescence. Upon reaching electric field strength of 120 kV/m, coalescence of droplets occurs.

Thus, the mechanisms of coagulation and coalescence of emulsion droplets in electric fields are revealed. The frequency at which coagulation and coalescence of emulsion droplets occur ranges, the times of establishment of these processes are determined. A tendency to increase the intensity of the processes under study with increasing field strength and salinity of the aqueous phase has been found. The critical intensities of the processes of coagulation and coalescence of the studied emulsions are established. The results will be used in mathematical modeling of the coagulation and coalescence of water-in-oil emulsion systems.

**Acknowledgments**

The research was supported by the grant of the Russian Science Foundation (project no.19-11-00298).

**References**

[1] Chen T et al. 1994 *Colloids and Surfaces A* **83**(3) 273–84
[2] Kovaleva L 2013 *High Temperature* **51**(6) 870–2
[3] Lundgaard L Electrocoalescence of water drop pairs in oil 14th Int. Conf. on Dielectric Liquids (Graz: IEEE XPLOR) pp 215–9
[4] Adamiak K 1999 Force of attraction between two conducting droplets in electric field *Annual Meeting IEEE* (Phoenix: IEEE) pp 1795–800
[5] Jones T et al. 2005 *Electromechanics of Particles* (Cambridge: Cambridge University Press)
[6] McLean J and Sullivan A. 1998 *Structures and Dynamics of Asphaltenes* (New York: Plenum Press)