Destruction of water-in-oil emulsions in electromagnetic fields

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Abstract. In this paper, we study the degree of exposure of electromagnetic fields to water-oil emulsions with different physical and chemical properties, as well as the characteristics of their heating and delamination when exposed to radio frequency and microwave frequencies in electromagnetic fields. Experimental research methods are described. The results of experimental studies of heating emulsions in radio frequency and microwave electromagnetic fields under dynamic conditions and the results of their separation are presented. As a result of the research, it has been found that when exposed to radio frequency or microwave electromagnetic fields on oil-water emulsions, the degree of heating and the efficiency of emulsion stratification depend on the total content of asphaltene and resins, the water content in the emulsion, and the operating frequency of the generator in the region of resonant frequencies for emulsions. For all types of emulsions, radio frequency action is more effective than a microwave field, with low water contents. With increasing water content the efficiency of microwave exposure increases. Also, with an increase in the water content, the intensity of heating the emulsion in the microwave field increases with the same energy inputs.

1. Introduction
One of the main tasks in the preparation of crude oil is the separation of water, that is, the destruction of oil-water emulsions. The essence of the separation of emulsions lies in the enlargement (coalescence, coagulation) of water droplets dispersed in oil with the subsequent removal of the formed layer of water. The water-in-oil emulsion is a heterogeneous system consisting of very small (up to 50 nm) water droplets dispersed in oil. Each drop is surrounded by a so-called 50–100 nm thick reservation shell, consisting of oil components. The reservation shell prevents coalescence of water droplets. Such emulsions are difficult to destroy by conventional methods (centrifugation, heating, the use of demulsifiers). One of the promising methods for the destruction of water-oil emulsions is the use of electromagnetic fields of the radio frequency and microwave ranges. In all cases we are talking about the resonant interaction of the field with matter.

Radio frequency (RF) electromagnetic field affects the polar components of oil - asphaltenes and resins. The maximum efficiency of this process is achieved when the frequency of the RF electromagnetic field coincides with the frequency of oscillation of the polar oil molecules. When this happens the structure of high-molecular compounds of oil is destroyed. In addition, electromagnetic energy is dissipated and transferred to thermal energy in the reservation shell. Thus, for the effective use of the RF electromagnetic field for the preparation of crude oil, it is necessary to measure the dielectric parameters of the crude oil first and to determine the resonant frequency in the RF range.

The microwave field polarizes the water molecules, thereby heating them. In addition to thermal heating, a decrease in the surface tension at the interface and in the viscosity of the oil occurs.
In the case of RF and microwave exposure, there is an intense heating of the oil-water emulsion. In the case of RF electromagnetic action, heating occurs due to polarization of the polar components of the oil. Under microwave exposure, heating occurs due to the polarization of water molecules. In addition, in the case of two-phase liquids, surface polarization is manifested at the interface [1–4].

It was shown in [5–6] that the microwave EM field not only contributes to heating and lowering the viscosity of the system, but also enhances the coalescence process. An increase in temperature affects a decrease in interfacial surface tension. According to this paper, the dielectric constant affects the probability of deposition. It was also revealed that the degree of separation depends only on the temperature of the aqueous phase and little depends on the average temperature of the emulsion. Moreover, as shown in [7], too high a microwave energy and a long radiation time are not effective for water separation. This is due to excessive boiling of the samples.

Thus, the destruction of oil-water emulsions in electromagnetic fields depends on many factors: the content and concentration of high-molecular compounds, the amount of water, the dielectric properties of oil-water emulsions, the frequency and intensity of the electromagnetic field, the time of exposure. Therefore, an urgent task in the development of electromagnetic methods for dehydration of oils is to study the characteristics of the effects of electromagnetic fields on oil-water emulsions with different physical and chemical properties under certain parameters of the electromagnetic field and to identify patterns of behavior of oil-water emulsions in the electromagnetic field.

The aim of this work is to study the degree of influence of RF and microwave electromagnetic fields on oil-water emulsions with various physical and chemical properties. In this regard, the following tasks: develop a laboratory bench for studying the influence of RF and microwave electromagnetic fields on oil-water emulsions in a dynamic mode; to investigate the degree of heating of oil-water emulsions in RF and microwave electromagnetic fields, depending on their physical and chemical properties; to investigate the degree of stratification of oil-water emulsions in RF and microwave electromagnetic fields, depending on their physical and chemical properties.

2. Material and methods

As objects of study, model water-oil emulsions prepared on the basis of real oils and formation waters were used. Water-oil emulsions were prepared with an aqueous phase content of 30, 50, 80% on an overhead stirrer at a rotation speed of 3000 rpm for 45 minutes at room temperature.

Table 1 presents the content of asphaltene, resins and paraffins in the studied oils and their physical properties.

| Oil     | Asphaltenes | Resins | Paraffins | Viscosity (25 °C) | tgδ (13.56 MHz) |
|---------|-------------|--------|-----------|-------------------|-----------------|
| Oil No.1| 0.67%       | 6.2%   | 5.1%      | 220 cps           | 0.005           |
| Oil No.2| 1.19%       | 16.6%  | 6.8%      | 310 cps           | 0.01            |
| Oil No.3| 3.2%        | 11.4%  | 3.75%     | 180 cps           | 0.02            |

The oil-water emulsion is processed by RF (13.56 MHz, 2.5 kW) or microwave (2.4 GHz, 2.8 kW) electromagnetic fields in a dynamic mode at a flow rate of 30 l/h. Figure 1 shows a schematic diagram of a laboratory stand for the study of RF and microwave exposure to oil-water emulsions in a dynamic mode. The original emulsion from the tank is pumped through the RF reactor or the microwave chamber with the magnetron system. The radiotransparent tube is installed inside the microwave camera. At the inlet and outlet from the RF reactor and the microwave chamber, emulsion temperatures are determined. The working volume of the RF reactor and radiotransparent tube in the microwave chamber is 200 cm3. After treatment, the dynamics of sludge is determined within 2 hours.
Figure 1. Schematic diagram of a laboratory stand for radio frequency and microwave electromagnetic effects on water-oil emulsions in a dynamic mode, where: 1 – emulsion tank, 2 – graduated cylinder, 3 – pumping station, 4 – RF reactor, 5 – temperature recorder, 6 – RF generator, 7 – microwave camera, 8 – magnetron system.

Since the degree of exposure of the RF electromagnetic field to oil or emulsion depends on the dielectric parameters and their dispersion, the frequency dependences of the dielectric loss tangent $\tan \delta$ were determined in the frequency range 0.1 - 35 MHz for the objects under study using the Q-factor Q560 (frequency range 50 kHz - 35 MHz). In Figure 2 shows the curves $\tan \delta (f)$ for the studied emulsions.

Figure 2. Curves $\tan \delta$ for emulsions.

3. Results
Table 2 presents the results of heating emulsions in RF and microwave electromagnetic fields.

The table 2 shows that for all the emulsions under study under RF electromagnetic action, heating is not strongly dependent on the water content in the emulsion. However, the intensity of heating the emulsion based on different oils in the RF electromagnetic field is different. This is due, firstly, to the content of polar components (asphaltenes, resins) in oil, and secondly, to the impact frequency in the region of resonant frequencies for oil and its emulsions. It is known that with increasing water content in an emulsion, the region of resonant frequencies slightly shifts to the region of low frequencies [5].
Table 2. Changing the emulsions temperature in RF and microwave electromagnetic fields.

| EM field type | RF 30% water | RF 50% water | RF 80% water | Microwave 30% water | Microwave 50% water | Microwave 80% water |
|---------------|--------------|--------------|--------------|----------------------|----------------------|---------------------|
| Oil No.1      | 8.5 °C       | 9.5 °C       | -            | 16.5 °C              | 29.0 °C              | -                   |
| Oil No.2      | 21.5 °C      | 23.0 °C      | 25.0 °C      | 12.0 °C              | 27.5 °C              | 49.0 °C             |
| Oil No.3      | 15.0 °C      | 16.0 °C      | 19.0 °C      | 15.0 °C              | 26.0 °C              | 46.0 °C             |

So, the total content of asphaltenes and resins in oil No. 1 is 6.87%, in oil No. 2 - 17.79%, in oil No. 3 - 14.6% and as can be seen from the table, the emulsion on the basis of oil No. 1 is heated the most slowly, and emulsions based on oil No. 3 are the fastest to be heated. In addition, the operating frequency of the RF generator enters the region of resonant frequencies for oil No. 3. That is, with oil emulsions No. 3, a resonant interaction of the RF electromagnetic field occurs, at which the maximum possible dissipation of electromagnetic energy in the emulsion in the form of heat takes place.

With microwave treatment on water-oil emulsions, the heating temperature is approximately the same for emulsions with different oils. However, the temperature of the emulsions increases with increasing initial water content in the emulsion. At the same time, the energy consumption for heating emulsions with different water contents is the same (0.1 kWh/kg).

After processing the RF and microwave electromagnetic fields, the dynamics of sludge of field-treated emulsions in terms of the volume of separated water was investigated. When exposed to water-oil emulsions of RF and microwave electromagnetic fields, separation of the emulsion occurs [5].

The mechanisms of coagulation and coalescence of oil-water emulsions under the action of RF and microwave electromagnetic fields are described in more detail in [3]. Studies were conducted at the micro level in a static mode. The authors have shown that under the action of a RF electromagnetic field, aggregates of droplets in the form of chains, predominantly elongated along the direction of the electric field lines, are formed.

The convergence of water droplets, due to the action of electrophoretic force, occurs until, at some distance, the forces of attraction are not balanced by the repulsive forces of the armoring shells of the droplets. At a critical electric field, the energy barrier of repulsive forces is surmounted and water droplets merge. The results of studies of the effects of the microwave electromagnetic field on the microstructure of various samples of emulsions have shown that water droplets become larger and coalesce when exposed to the microwave electromagnetic field.

Figure 3 shows the dynamics of sludge emulsions with oil No. 2 after treating RF and microwave electromagnetic fields, from which it can be seen that for 30% and 50% emulsions, the amount of water separated from the RF reactor is higher than the amount of delaminated water from the microwave cameras. For an 80% emulsion, the amount of exfoliated water at the outlet from the microwave chamber is higher than at the exit from the RF reactor and reaches 75%. That is, with an increase in the water content in the emulsion, the efficiency of the microwave electromagnetic field increases.

Similar results were obtained with other test emulsions. It was found that for all types of emulsions, the RF field works more efficiently than the microwave field at low water contents. With increasing water content, the efficiency of the microwave field increases. Under RF exposure, the separation of the emulsion occurs during the treatment in the reactor, and at the outlet from the reactor we have a high proportion of exfoliated water. At microwave exposure to 30% and 50% emulsions, the dynamics of sludge is slower. This is explained by different mechanisms of destruction of emulsions in the RF and microwave fields. Not only polar oil molecules are polarized in the RF field, but also the water droplets, covered with a armoring shell, which leads to their coagulation, and as a result, to coalescence.
Figure 3. The dynamics of sludge emulsions after RF or microwave electromagnetic heating.

Conclusions
As a result of the research it has been found that when exposed to RF or microwave electromagnetic fields on oil-water emulsions, the degree of heating and separation efficiency of the emulsion depend on the total content of asphaltenes and resins, the water content in the emulsion, and the operating frequency of the generator in the region of resonant frequencies for emulsions.

For all types of emulsions, RF exposure is more effective than a microwave field, with low water contents. With increasing water content the efficiency of microwave exposure increases. With an increase in the water content, the intensity of heating the emulsion in the microwave field increases with the same energy inputs.

The results will be useful in developing recommendations for the industrial use of RF electromagnetic effects on oil reservoirs.

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

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