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## Practice of using the magnetic treatment devices to intensify the processes of primary oil treating

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**Abstract.** During the primary treatment of oil, gas and water, complications arise associated with the presence of hard water-oil emulsions, which cause an increase in fluid pressure in the gathering systems, pipeline damage, as well as difficulties in gas separation and preliminary water discharge at the preliminary discharge unit (PRU). Additional problems arise during transportation of highly paraffinic oils associated with the crystallization of paraffin in the flow path of the oilfield equipment and on the inner surface of pipes, leading to a drop in the productivity of pipelines.

Article discusses the technology of magnetic-reagent treatment of water-oil media, which allows intensifying the processes of primary oil treatment at the facilities of its production. Bench and pilot tests have shown the ability of the magnetic field to accelerate oil demulsification processes, increasing the percentage of separated water during subsequent settling, and to reduce asphalt-resin-paraffin deposits (ARPD) on the inner surface of oil and gas field equipment.

Mechanism of the magnetic field effect on water-oil media is described. Effect of treatment on the integrity of the armour shells of oil-water emulsions was studied. Various modes of magnetic treatment have been investigated with evaluation of its effectiveness. It is shown that the best effect is achieved with the combined use of reagents and a magnetic field. Synergistic effect is observed, which consists in increasing their effectiveness. This made it possible to conclude that this method can be applied to reduce the consumption of reagents used in oil production while maintaining the treatment efficiency.

**Key words:** magnetic treatment; magnetic and hydrodynamic treatment; destruction of emulsions; oil demulsification; intensification of oil treatment; countering asphalt-resin-paraffin deposits; pulse magnetic treatment; reduction of reagent consumption

**Introduction.** Since the 60s of the twentieth century, attempts are being made in the petroleum engineering to introduce magnetic treatment apparatus (MT) into the technological processes of gathering and field treatment of oil, gas and water. A lot of positive results of pilot tests and implementations of various designs of MT apparatus for treating the water-oil media that are extracted or injected into the reservoir and transported through pipelines, in order to change their physical and chemical activity and rheological properties, are known.

Despite the convincing achievements in the field of magnetic treatment of oilfield media (works by V.I. Lesin [4, 5], A.Kh. Mirzadzhanzade [6, 7] and others [2, 10, 14, 17]), there are problems associated with low repeatability of satisfactory results in practice.

Due to the specifics of oilfield equipment, the most widespread are the apparatus with permanent magnets, which are easy to assemble and do not require special training of service personnel [16]. But the existing drawbacks, which are low intensity of the magnetic field (MF), the inability to regulate the treatment parameters for the changing physical and chemical properties of the pumped medium, as well as the ability to accumulate ferromagnetic impurities during operation [13] on the surface of permanent magnets, did not allow their application for a wide range of tasks. Another type of devices used – electromagnetic devices – has a fundamentally different design, however, a problem similar to apparatus on permanent magnets is their low magnetic field intensity [8].

As a result of the analysis of theoretical explanations for the physical principles of operation and the indications of the mathematical apparatus for calculation of the devices for magnetic and hydrodynamic treatment of water-oil media flows, we found that these devices were calculated and



used under conditions of a laminar flow of a liquid. Under these conditions, a scheme is justified, in which the lines of magnetic induction are directed perpendicular to the velocity vector of the unit volumes of liquid. However, when the flow is turbulized, chaotically directed vortices are formed in it, the velocity vector of which, in contrast to the laminar flow, is directed not along the generatrix of the pipeline, but perpendicular or at an angle to the generatrix. In this case, the direction of the magnetic induction vector may not be perpendicular to the flow vector, but coincide with it or be at an angle. Vortices in a turbulent flow move chaotically and often in opposite directions. On the one hand, it increases the hydraulic resistance, and on the other hand, this makes it possible to increase the efficiency of the magnetic effect, at which, for example, the contact probability of suspended oil globules with a surface charge changed in a magnetic field increases.

Thus, the scheme and the calculated dependencies of the magnetic treatment can be applied to the MT scheme using a solenoid – the direction of the magnetic induction lines coincides with the direction of the flow. To obtain the maximum values of the magnetic induction of the magnetic fields with a high intensity created in the solenoid, capable of exerting a maximum effect on the treated medium, the developed apparatus uses a pulse-treating mode [12]. Pulse magnetic device (PMD) consists of a low-frequency current generator and a solenoid connected to it by means of a cable, flanged to the pipeline section (Fig.1).

Fluid flowing through a non-magnetic pipeline that is part of the solenoid is exposed to strong magnetic fields (400 kA/m). Low surface roughness, as well as the solidity of the structure (no transitions caused by the need to install permanent magnets) prevent the possible deposition of impurities in the device. Generator of current pulses provides a change in the current pulse repetition frequency within the range of 0-50 Hz. Adjustment is required due to the need to select the optimal treatment parameters for water-oil media with different physical, chemical, structural and mechanical properties.

Electromagnetic devices used in the practice of oil production [9] operated in a relatively wide frequency range. After a large number of experiments, the upper frequency limit in our setup was limited to 50 Hz due to a decrease in efficiency with a further increase in the pulse frequency. To generate strong pulse magnetic fields (1.2 T) in the storage and technological unit of the PMD, a capacitor is used as the most efficient source of energy. In this type of design, the frequency of the magnetic field is inversely related to the energy given off by the capacitor. Since there is a direct relationship between the energy stored in the capacitor and the energy of the magnetic field in the solenoid, increasing the frequency will reduce the intensity, and hence the current passing through the solenoid, and, as a consequence, will reduce the efficiency of magnetic treatment.

**Destruction of oil-water emulsions.** Significant complications in the technology of oil production, gathering and treatment are caused by watering of productive formations of the oil fields. These complications are associated with the forming oil-water emulsions with high values of viscosity and resistance to destruction [1]. Main method for the destruction of hard emulsions in the field (treatment of oil-contaminated wastewaters with complex composition) is the in-pipe demulsification method, based on the addition of a demulsifier reagent to the product during its transport. When reagents are introduced into an oil emulsion, the following processes take place at the oil-water interface:



Fig.1. Installation “PMD-2” at the test object



demulsifier, which has a greater surface activity, displaces natural stabilizers – emulsifiers, while adsorbing on the interface of the oil globule. Molecules of demulsifiers change the wettability that facilitates the transition of these particles from the interface into the bulk of the water or oil phase, which leads to coalescence.

Investigations carried out by the authors of this article [18] showed that as a result of magnetic treatment of water-oil media, the surface tension at the oil-water interface decreases by 20 %. A drop in the stability of the dispersed system is observed, caused by a change in the polarity of the molecules at the interface. Since the mechanisms of effect for the magnetic field and the demulsifier that reduce the stability of oil-water emulsions are fundamentally similar to each other, it was suggested that magnetic treatment can intensify the processes of in-pipe demulsification.

**Methodology for the experiment 1.** A bottle test was used to assess the effect of magnetic treatment on the rate of settling for oil-water emulsions and to study the possible synergistic effect of the joint work of the magnetic field and the demulsifier. Method consists in determining the volume of water released from the oil emulsion in graduated vessels at regular intervals.

During the tests, oil samples were treated by a magnetic field both in the presence of a demulsifier and without it. Readings were taken at regular intervals (5, 15, 30, 45 min; 1, 2, 3, 4, 12 and 24 hours). Water-oil emulsion that did not contain chemicals and surfactants was used as an object of the study; the residual water cut was 57-58 %, and a demulsifier “Reapon” was used as a chemical.

The following treatment options were tested:

- BLANK – emulsion sample not treated by the magnetic field (MF) or demulsifier (DEM);
- 15 (7.5 and 3.5) mg/l DEM – emulsion sample treated by a demulsifier with different dosage (respectively 15; 7.5; 3.5 mg/l);
- 15 (7.5 and 3.5) mg/l DEM + MF – emulsion sample treated by a demulsifier with different dosage and magnetic field (respectively 15; 7.5; 3.5 mg/l);
- MF – emulsion sample treated only by magnetic field.

For all combined options (DEM + MF), the reagent was dosed first, and then treatment by a magnetic field was done.

Liquid was pumped through the test bench at a speed of 3 m/s through a tube 10 mm in diameter. Reynolds number was 6830.

Figure 2 shows the results of tests to assess the effect of different treatment options for an oil-water emulsion on the rate of its settling.

**Results of the research 1.** Treatment of oil-water emulsions by a magnetic field accelerates the settling process. Percentage of separated water is increased 4 times (from 4 to 18 %), compared to the untreated emulsion. Growth of sedimentation dynamics is explained by the fact that the MF acts on the armor shells of oil globules, including ferromagnets (iron oxides) and paramagnets (ARPD). Forces of electrostatic repulsion and intermolecular attraction (van der Waals) act on the globules in

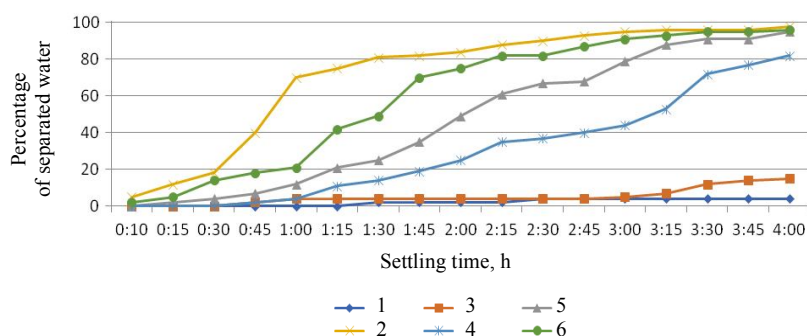


Fig.2. Emulsion dehydration curves

1 – BLANK; 2 – 15 mg/l DEM + MF; 3 – MF; 4 – 7.5 mg/l DEM; 5 – 15 mg/l DEM;  
6 – 7.5 mg/l DEM + MF

the emulsified state; the action of these forces is compensated and prevents coalescence. As a result of the magnetic effect on the molecules of these substances, magnetic forces, which coincide in direction with the electrostatic forces, act additionally [11]. If in a static state the particles are in chaotic, Brownian motion, then when introduced into a magnetic field, they line up along the magnetic induction vector in the direction of



the action of the electrostatic repulsion force. This behavior is due to the similarity of the nature of forces.

Since the molecules of ferromagnets and paramagnets are easily oriented in a magnetic field, they coagulate as a result of magnetic interaction. Orientation of these particles (retraction, attraction) is determined by the gradient of the magnetic field intensity (the change in the magnetic field over time). Pulse magnetic device surpasses all competitors by this parameter and shows the best effect.

2. Combined treatment by a reagent (demulsifier) and an electromagnetic field leads to an increase in efficiency, a synergistic effect is manifested – the combined action surpasses the separate effect of a reagent and MF. With the joint participation of a magnetic field and a demulsifier, the work of magnetic forces reduces the free surface energy of the system. A decrease in interfacial energy facilitates the coagulation of water globules. As a result, it is possible to accelerate the dissociation processes at the same concentration of the demulsifier, or to reduce its consumption, while maintaining the duration of demulsification.

3. The effect of sequential treatment of the emulsion by a reagent with a dosage of 7.5 mg/l and then by a magnetic field is comparable to the effect of treatment of oil by a reagent with a dosage of 15 mg/l. Separation of water is no less than 90 % for the period of settling 3-3.5 h.

4. Combined treatment of the emulsion by a reagent with a dosage of 15 mg/l and a magnetic field reduces the settling period for the separation of at least 90 % of water to two hours. Manifestation of a synergistic effect from physical and chemical impact allows recommending the application of this treatment method to reduce the consumption of reagents used while maintaining the treating efficiency.

**Assessing the effectiveness of ARPD reduction/prevention.** Another major problem in oil production, causing complications in the operation of wells, oilfield equipment and pipelines is asphalt-resin-paraffin deposits (ARPD). Their accumulation in the flow path of oilfield equipment and on the inner surface of pipes leads to a drop in system performance, a decrease in the overhaul period of wells, a decrease in the efficiency of pumping units and a number of other problems.

The most widely used method of countering the ARPD is the chemical method, which consists in dosing reagents to the produced (transported) product of the wells that reduce, and in some cases completely prevent, the formation of deposits. Action of the reagents-inhibitors of paraffin deposition is based on the adsorption processes occurring at the interface between the liquid phase and the solid surface [15].

Disadvantages of this method include the complexity at the selection of an effective reagent associated with periodic changes in operating conditions during field development, as well as significant economic costs due to high dosages of reagents (in some cases, the values reach 400-450 g/t).

At present, it is not possible to completely exclude chemical methods of countering the ARPD, since there are no alternative methods on the market that equally possess all their advantages. In this regard, oil enterprises are actively looking for possible ways to reduce the consumption of reagents.

One of the most promising methods is the considered technology of oil treatment by a magnetic field. It has been established [3] that under the effect of magnetic fields on a moving liquid, the destruction of aggregates consisting of submicron ferromagnetic microparticles of iron compounds occurs, which are in typical concentrations of 10-100 g/t in oil and associated water. Each aggregate contains from several hundred to several thousand microparticles; therefore, the destruction of aggregates leads to a sharp (100-1000 times) increase in the concentration of crystallization centers for paraffins and salts and the formation of micron-sized gas bubbles on the surface of ferromagnetic particles. As a result of the destruction of aggregates, paraffin crystals precipitate in the form of a finely dispersed volumetric stable suspension, and the growth rate of deposits decreases in proportion to a decrease in the average size of paraffin crystals precipitated together with resins and asphaltenes into the solid phase (Fig.3).

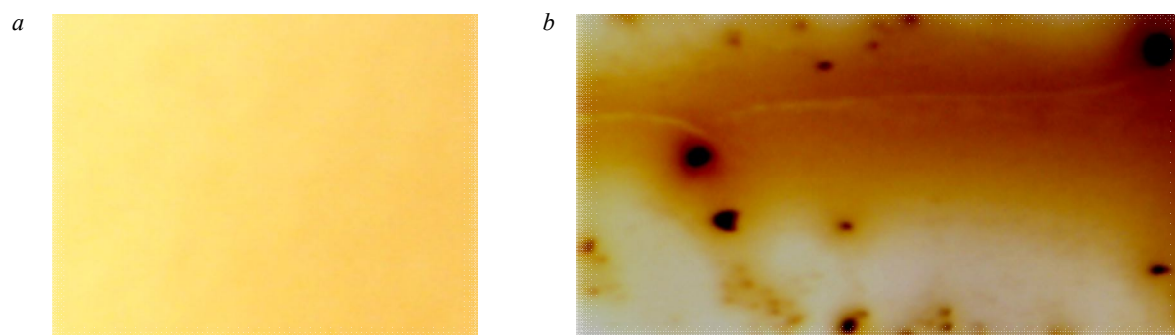


Fig.3. An increase in the centers of crystallization for ARPD after MF: *a* – before magnetic treatment; *b* – removal of coagulated ARPD structures by flow

**Methodology for the experiment 2.** To determine the effectiveness of reducing the ARPD under various options for magnetic treatment of oil, the “Cold finger test” method was used (“Cold rod”, RD 39-3-1273-85). This method makes it possible to determine the effectiveness of ARPD reduction/prevention and optimize the concentration of the inhibitor, since it takes into account all stages of the process: the formation of crystallization centers, the growth and deposition of paraffin crystals and heavy oil components (resins and asphaltenes), their destruction (dispersion) under the action of a moving oil flow. Method is based on measuring the difference between the amount of ARPD deposited on the rod surface without oil treatment and the amount of ARPD deposited on the rod surface after oil treatment by a magnetic field.

As a test medium, bottom oil was used, not treated with depressant or other additives that reduce ARPD, with the following characteristics: density at 20 °C – 0.817 g/sm<sup>3</sup>; viscosity at 20 °C – 5.09 mm<sup>2</sup>/s; paraffin saturation temperature for oil 22.5 °C; oil pour point 9 °C.

Following oil treatment options have been tested:

- BLANK (blank sample – oil sample without treatment by magnetic field or depressant);
- 400 (300, 200) mg/l DP (oil sample with 400 mg/l depressant);
- 300 (200) mg/l DP + MF (oil sample with 300 mg/l depressant and subsequent treatment by magnetic field);
- MF (oil sample treated by magnetic field).

All treatment options tested were evaluated with oil preheating. For the combined options (DP + MF), the reagent was dosed first, and then treatment by a magnetic field was carried out.

The table shows the results of tests to assess the effectiveness of the influence of various treatment methods on reducing ARPD.

**Test results**

| Type of treatment | Day 1 |      |      | Day 2 |      |      | Day 3 |      |      |
|-------------------|-------|------|------|-------|------|------|-------|------|------|
|                   | E1    | E2   | Eav  | E1    | E2   | Eav  | E1    | E2   | Eav  |
| 400 mg/l DP       | 64.1  | 63.4 | 63.8 | 53.4  | 61.5 | 59.9 | 58.2  | 56.6 | 57.4 |
| 300 mg/l DP + MF  | 70.6  | 73.2 | 71.9 | 57.5  | 60.3 | 58.9 | 46.3  | 47.4 | 46.9 |
| 300 mg/l DP       | 56.5  | 56.9 | 56.7 | 49.6  | 47.8 | 48.7 | 44.0  | 43.5 | 43.8 |
| 200 mg/l DP + MF  | 43.6  | 42.1 | 42.8 | 33.7  | 35.1 | 34.4 | 30.4  | 28.7 | 29.5 |
| 200 mg/l DP       | 36.5  | 35.9 | 36.2 | 23.9  | 29.3 | 29.3 | 24.4  | 30.0 | 27.2 |
| MF                | 25.3  | 24.3 | 24.8 | 12.6  | 15.0 | 13.8 | 12.8  | 10.7 | 11.7 |

Note. E1, E2 – result of measuring the treatment efficiency.

**Results of the research.** 1. It is shown that for turbulent flows of field fluids, a magnetic treatment scheme with coincident vectors of fluid flow velocity and magnetic induction can be applied.



2. Integrated treatment by a low-frequency electromagnetic field and a reagent leads to an increase in efficiency, a synergistic effect is manifested – the combined effect exceeds the separate effects of a reagent and an electromagnetic field;

3. For all treatment methods, the greatest effect was found on the first day. Further, after the second and third days, the efficiency decreases.

4. Effect of sequential treatment of oil by a reagent with a dosage of 300 g/t and then a magnetic field in comparison with the effect of treatment of oil by a reagent with a dosage of 400 g/t is at the level of 60-72 %;

5. Oil treatment by a pulse magnetic field can reduce the consumption of used deparaffining reagents by almost two times, while simultaneously increasing the efficiency of the operations. Combination of methods allows improving the technology of countering paraffin deposition in the oil and gas industry by increasing the efficiency of the reagents and reducing their consumption.

**Conclusion.** Obtained research results have shown the practical feasibility of using the technology of magnetic-reagent treatment to intensify the processes of primary oil treating. When treating oil-water media by a magnetic field, intensification of the demulsification processes is observed (the percentage of separated water increases during subsequent settling) and deparaffining (the intensity of ARPD formation on the inner surface of oil and gas field equipment decreases). With the combined use of magnetic and reagent treatment, a synergistic effect is observed, which consists in increasing the efficiency of demulsifiers, deparaffining agents and reducing their consumption. Given dependencies are in sufficient agreement with similar investigations on the application of magnetic treatment in the oil and gas industry.

Results of the research and the technology of magnetic-reagent treatment can be used at oil production facilities to increase the efficiency of existing technological processes for treating raw materials. The method itself can be considered cost-effective, since the implementation of the proposed technology does not require a large-scale reconstruction (MT apparatus is installed in the existing technological chain at the initial stage of treatment) and large material costs.

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