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Research Article

QUALITY IMPROVEMENT OF OIL-CONTAMINATED WASTEWATER, MEANT FOR INJECTION INTO FORMATION, USING TWO-STAGE TREATMENT TECHNOLOGY

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ABSTRACT

The paper deals with water conditioning issues in oil-field development using water-flooding. It is common knowledge that injected water contains oil residues and mechanical impurities, which affect permeability of geological horizon. It has been shown that these water impurities could intensify rock colmatation up to a full clogging of pores and fractures. Hence, issues of improving quality of injected water, aimed to ensure enhancement of reservoir properties, have been studied from a variety of new angles. There are given results of conducted test experiments as well as detailed description of elaborated equipment design. It has been established that two-stage treatment technology proposed in the paper, by making use of magnetic treatment device and sewage tank with liquid hydrophobic layer, will allow to considerably improve quality of injected water. Suggested water treatment unit appears to be highly applicable, providing a maximum effect at a minimum material cost.

Keywords: oil, reservoir colmatation, oil-contaminated wastewater, formation contamination, water conditioning, magnetic treatment, fractured and disperse rocks.

INTRODUCTION

At the present moment most of oil deposits in Russia and CIS countries are developed using water-flood operation that consists in water injection aimed to maintain reservoir pressure. With a steady rise of water encroachment level into the gas and oil, the content of extracted from the stratum water consistently increases. In recent years water encroachment level in some cases has attained more than 90%. Existing water preparation equipment is not designed to cope with such volumes of produced reservoir water, which results in untreated water injection into the stratum. That kind of water contains oil globules and mud solids that eventually lead to decrease of reservoir permeability, drop of oil recovery rate and mineral resources gluttony [Golubev 2013]. The greatest influence on this process is exerted by suspended solids of different nature present both in water and adjacent formation. It has been established that, while being injected, solid particles together with oil residues and impurities are clogging pores, channels and fissures of enclosing rock, thereby reducing its permeability.

To reveal the dynamics of rock permeability alteration during filtration of fluids with different contamination level, experimental studies using microcinematography have been conducted. Enclosing rocks were substituted by a uniform layer of poorly sorted quartz sand with thickness of 2530 mm and heterogeneity coefficient 1.62. Permeability coefficient was changing within the range 0.8–2.1 m/day. Through the sand layer was conducted wastewater containing suspended solid particles (not exceeding 63 mg/dm^3), oil products (up to 250 mg/dm^3), and ultrapurified water (particles size lesser than 0.2 μ).

Experiments carried out confirmed that whatever the contamination level of water is, its subsequent filtration through the rock is followed by decrease in permeability and reduction in sizes of solid particles in the filtrate. Notably, while injecting ultrapurified water, permeability decrease rate is about 0.15% per 1 unit of pumped over fractured-porous volume, whereas in case of untreated river-water it attains 2.2%. After filtration of 130 and 36 volumes of porous water, permeability decrease rate goes down to 0.02 and 0.17% respectively.

Thus, injecting into formation treated water considerably enhances oil displacement conditions and promotes improvement of reservoir characteristics. In addition, there can be observed oil displacement enhancement from a greater number of porous-fractured channels and oil recovery increase.

In this regard, it is a matter of considerable importance to develop efficient technical and technological solutions providing better water treatment. It should be mentioned that traditional methods of mechanical purification in many cases do not maintain the compliance with strict modern requirements specified to the quality of treated wastewater meant for being injected into formations.

MATERIALS AND METHODS

For the moment there are several scenarios of oil-contaminated wastewater treatment. Method selection is defined by water volume, its composition, physical-chemical characteristics and purified water requirements.

Main methods can be divided into:

- gravity separation (desilting, hydro cyclonage, centrifuge treatment);
- mechanical separation by way of filtration;
- purification by means of globules agglomeration (coagulation, flotation, hydrodynamic drop formation, etc.).

However, as a matter of actual practice, these methods do not allow purify water up the quality defined by standards: 0.05 mg/dm^3 – for water discharged in drinking water basins, 5.5 mg/dm^3 – for water injected into geological formation. For instance treatment by abovementioned methods decreases oil-products content down to 50 mg/dm^3 and mechanical impurities content – down to 12 mg/dm^3 [Golubev 2000, Ivanov 1956]. The only existing nowadays way to attain high wastewater quality is to combine several treatment methods, using chemicals at specified stage of technological process.

Described method has following shortcomings: high cost, complex procedure of selecting reagent according to wastewater physical-chemical characteristics, secondary contamination due the use of chemical agents.

For that matter, one of the most critical tasks for oil-producing enterprises consists in enhancing quality of wastewater treatment by upgrading existing treatment facilities. Developing technology of wastewater treatment by means of magnetic field appears to be the most effective way.

At the present day there are known a lot of positive results of using magnetic water systems in different branches of industry: chemical, mining, metallurgical, oil, build-and-construction, as also agricultural. Literature survey together with on-the-farm research experience, aimed to discover magnetic field effect on oil-in-water systems, allow us to reasonably believe in possible use of magnetic treatment in the area of water conditioning, in order to purify it from oil and mechanical residues [Laptev 1999, Lutoschkin 1977, Patent 2094081 RF 1997].

Studying magnetic field effect on oil-in-water system has been performed using designed and manufactured laboratory unit, which included control unit (surge-current generator) and solenoid coil with connecting branches providing input and output of liquid processed (Figure 1).

The laboratory unit operates as follows: liquid stream, while passing through the solenoid coil, undergoes processing by low-frequency pulsed magnetic field with given frequency. Solenoid coil is presented by a section of pipeline made of nonmagnetic substance with copper coils on the body. For laboratory conditions there has been taken an open flow area of 16 mm, with a length of 750 mm.

Pulsed electromagnetic unit operates as follows: rectified voltage from the system rectifier is applied on reserve capacities, which serve as barrier capacity and main energy accumulator (Figure 2). Afterwards energy goes from the filter to charge-discharge unit (CDU) with capacity energy accumulators. Control signals received from the control system, which produces impulses with different repetition frequency, come to the CDU and then to the active reactor, represented by solenoid.

Before the experiments test solutions with oil content 250 mg/dm^3 had been prepared. Oil, used as a water contaminator, exhibited follow-

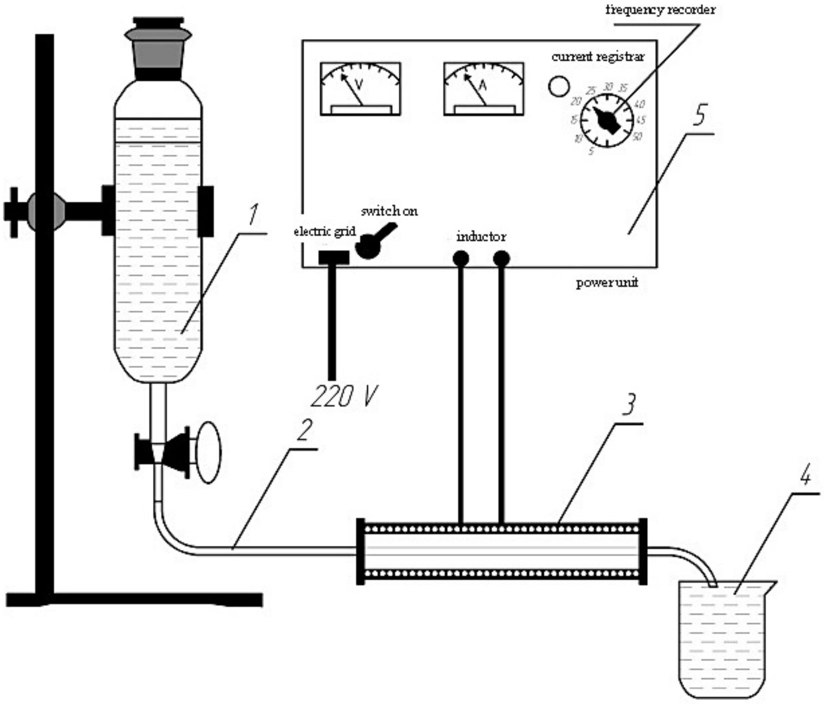

Figure 1. Basic configuration of laboratory unit

1 – reservoir with studied oil-contaminated liquid; 2 – connecting branches; 3 – solenoid coil; 4 – reservoir to separate water and oil phases; 5 – surge-current generator of low frequency with control unit.

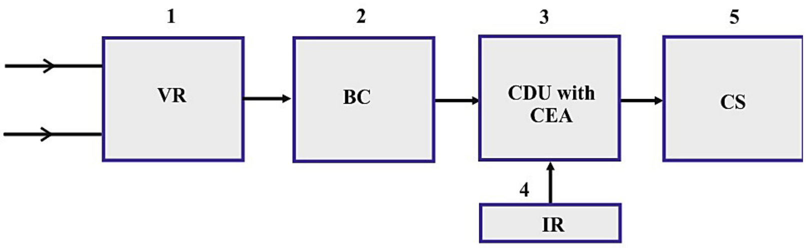

Figure 2. Generator functional design

1 – voltage rectifier; 2 – barrier capacities; 3 – charge-discharge unit with capacity energy accumulators; 4 – control system; 5 – inductive reactor.

ing properties: at 23°C viscosity – 87 mPa·sec, density – 930 kg/m^3. Measurements have been conducted according to Industrial Standard 39–133–81 "Water for reservoir flooding. Determination of oil content in produced wastewater" on analyzer Horiba OCMA-350 using spectrophotometric method.

Estimation of magnetic treatment efficiency involved determination of residual oil in water. During the analysis one water sample was left to settle down, whereas another was treated with magnetic field by way of single piping through the solenoid. Processed oil-water emulsion was poured into the flask and left to settle down as well. Residual oil content measurements were carried out after 15, 30 and 60 minutes. Such time intervals were chosen based on operating data of real industrial clarifying basins. Results acquired showed, that magnetic field accelerates natural splitting of processed oil-water emulsion during its settlement (Table 1, 2).

Considering that existing static, dynamic mud tanks do not provide high level of water purification from oil and mechanical residues (even intensification of water conditioning using magnetic treatment shows the maximum effect only after 60 minutes of such procedure), it is recommended to use clarifying basin with hydrophobic layer, which makes it possible to capture separated by magnetic field oil globules right at the input of the laboratory unit. Hydrophobic film in such a tank act as contact mass, absorbing water impurities.

Table 1. Petroleum hydrocarbons content in water without magnetic field treatment, in time

Time, min	15	30	60
C, mg/dm^3	33	25.3	15.7

Table 2. Petroleum hydrocarbons content in water after treatment by magnetic field with frequency 15 Hz, in time

Time, min	15	30	60
C, mg/dm^3	13.2	7.2	6.5

Suggested mud tank design consists of the body 1, separating walls 2 and 3, intake pipeline 4 for contaminated water, dispersing units 5–7, outlet line 8 for oil, gate valve 9, pressure controller 10, level controller 11, outlet line 12 for purified water, gate valve 13 (Figure 3).

Mud tank operating principle is following. Mud tank is filled with water and oil layer. Treated water is delivered via connecting pipe to dispersing units, which are located inside the tank above the oil layer in such a way, that spray would be discharged uniformly across the oil surface. Delivered water by means of dispersers in the form of rain gets onto the oil surface, further passing through the oil layer, which retains oil particles contained in the treated water. Then water flows in a pipeline to the second compartment, where it undergoes another cleaning cycle. During mud tank operation the amount of oil is constantly growing at the expense of captured oil particles [Laptev 1999].

At the present day industrial facilities are extensively using mud tanks with hydrophobic layers OGV-G, which allow purifying water down the oil content 50 mg/dm^3 [Ivanov 1956]. Laboratory tests performed using designed model of such a tank indicated that during water filtration through the hydrophobic layer oil particles greater than 20 μ are captured best of all. Therefore, filter effectiveness might be heightened, if contaminating particles were preliminary aggregated with the aid of magnetic treatment unit, contributing to particles agglutination and aggregation up to the size of 60 μ.

Purification process in the suggested technology is performed as follows: oil-contaminated water with mechanical impurities is exposed to an intense impulse magnetic field, adjusted experimentally. Treated water arrives to the mud tank OGV-G, where it is purified due to the passage through the hydrophobic oil layer. Oil film in such a tank acts as contact mass, which by virtue of sorption processes absorbs water polluting matter.

To carry out the experiment a laboratory bench has been assembled. It consisted of magnetic treatment unit 1 and mud tank model 2 (Figure 4). During the test modeled wastewater solution was analyzed, in the same manner as in the experimental study of magnetic field influence on oil-in-water systems. Treatment with magnetic field was conducted at the frequency 15 Hz.

RESULTS

Study results with account of previous experiments are presented in the Table 3.

Table 3. Experiment results

Experiment		Result, mg/dm^3
Water sample after static settling-out during:	15 min	33
	30 min	25.3
	60 min	15.7
Water sample after magnet field treatment and static settling-out during:	15 min	19.5
	30 min	15
	60 min	6.5
Water sample after purification using OGV-G device:		25
Water sample after two-stage treatment:		5.4

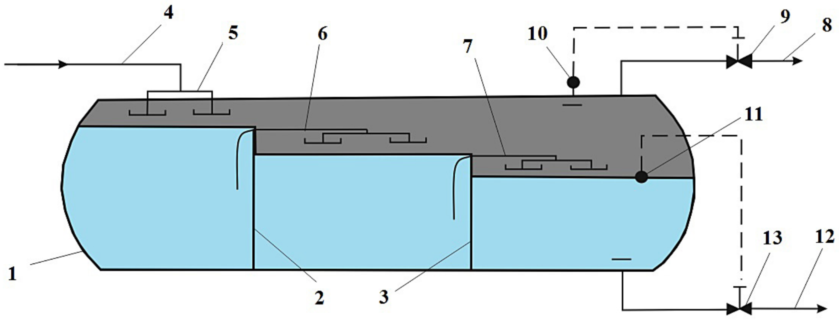

Figure 3. Mud tank with hydrophobic filter

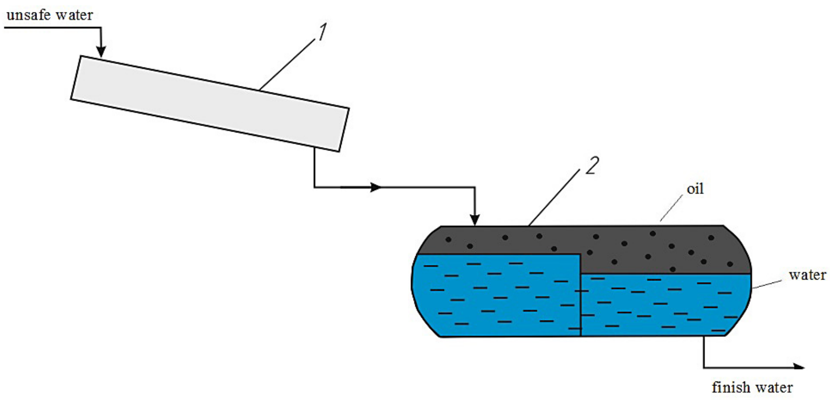

Figure 4. The concept of laboratory bench with two-stage technology of water treatment

Value acquired (5.4 mg/dm^3) while using cross-flow (dynamic) treatment technology, is less than after static settling-out during 60 minutes. That is to say, using mud tank with hydrophobic layer as a post-treatment equipment provides an enhanced level of water purification up to the quality standard.

CONCLUSION

With an increase of water contamination level the number of firmly clogged fractures, channels and pores in oil-bearing strata grows, which triggers reservoir characteristics deterioration. Enhancing oil recovery rate is possible in case of high quality water treatment. Oil-contaminated wastewater treatment by low frequency magnetic field accelerates process of succeeding natural phase splitting during settling-out that increases method economic efficiency.

Based on conducted experiments, it has been established that magnetic treatment of half-purified water appears to be more effective when performed in cooperation with designed OGV-G unit. Hydrophobic layer of the latter, used as sorption material, improves quality of wastewater purification up to required standard on account of particles agglomeration. Implementation of technology suggested in oil-developing branch will provide increased quality of water injected into formation, avoidance of significant expenses on reconstruction of water treatment facilities, and enhancement of ecological situation in the enterprise area.

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