Laboratory study of the oil displacing ability of a chemical acid oil-displacing composition

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Abstract. The paper presents the results of laboratory experiments to study the filtration characteristics of models of a heterogeneous reservoir of a Permian-carbon deposit in the Usinsk mine and the oil-displacing ability of a chemical acid oil displacing composition (AODC). The experiments were carried out on a setup for studying the filtration characteristics of heterogeneous reservoir models. The study found that the use of AODC will lead to a significant increase in the coefficient of oil-displacement.

1. Introduction

The share of hardly recoverable reserves in the balance of our country’s reserves is constantly growing, along with a long-term decline in the oil-recovery coefficient [1, 2]. In Russia, as well as abroad, there is a constant increase in the share of high-viscosity oil in production. The share of hardly recoverable oil fields in the Russian Federation reached 70% with an oil-recovery ratio of about 35%, which is one of the lowest rates in world practice [3].

Currently, the most common methods used to increase oil-recovery are water flooding, methods of thermal action on the reservoir, such as steam-cyclic treatment of wells and injection of hot water or steam into the reservoir, gas and physic chemical methods, each of which has its own field of applications [4-9].

Physicochemical methods for increasing oil-recovery are mainly based on the displacement of oil by aqueous solutions of various chemicals that improve or change the displacing properties of water to the necessary directions [1]. The most common are technologies founded on the introduction of water-soluble surfactants [10], polymers, acids and alkalis, solutions of inorganic salts, and micellar solutions into the oil reservoir [11]. Their action is based on a decrease in interfacial tension between oil and water (surfactants, alkalis) and the elimination of capillary forces in the water flood, leading to an increase in oil-displacement coefficient [10].

To increase the oil-recovery coefficient by enhancing the permeability of reservoir rocks and the productivity of producing wells, as well as increasing the oil-displacement coefficient, an acid chemical oil-displacing composition based on a surface-active substance (surfactant), inorganic acid adduct and polyhydric alcohol was developed at the Institute of Petroleum Chemistry of the SB RAS. The composition is compatible with saline formation water, has a low freezing temperature (minus 20 ÷ minus 60 °C), low interfacial tension at the oil border (below 0.001 mN/m at the border with oil of the Usinskoye mine). The density of the composition can be regulated from 1100 to 1300 kg / m³, viscosity – from tens to hundreds of MPa·s. The composition has a delayed reaction with
carbonate rocks. High oil-displacing ability, compatibility with mineralized formation waters, reduction of clay swelling lead to additional washing out of residual oil from both high-permeability and low-permeability zones of the reservoir [8, 10].

The paper presents the results of laboratory studies of the filtration characteristics of a model of a heterogeneous reservoir of a highly viscous oil deposit and the effectiveness of using an acidic chemical composition in the process of displacing high-viscosity oil.

2. Materials and methods

The study of the oil displacement process was carried out on the installation to study the filtration characteristics (KATAKON LLC), which allows modeling heterogeneity of the oil reservoir. To conduct filtration tests, were prepared models of a heterogeneous reservoir of a Permian-carbon deposit of the Usinsk mine. Each heterogeneous reservoir model consisted of two parallel columns filled with disintegrated carbonate core material and having a different gas permeability (Table 1). For modeling the oil-displacement process, we used the model of stratal water of the Usinsky field Permian-carbon deposits with a mineralization of 62.1–74.7 g/l and the oil model of the Usinsky field Permian-carbon deposits (thermostabilized oil diluted with kerosene in the oil: kerosene weight ratio of 70:30). The columns were sequentially saturated with a reservoir water model and a reservoir oil model. After oil saturation, the columns were installed in the heating circuit for the experiment.

The study of the process of oil-displacement using an acidic chemical oil displacing composition was carried out under conditions simulating the natural mode of development at a temperature of 20–23 °C, as well as under thermal and steam-cyclic exposure at a temperature of 150 °C. The effectiveness of the use of an acidic chemical oil-displacing composition was studied in the primary displacement of oil and in the process of completing the displacement of residual oil with water from two parallel columns with different permeabilities.

The experiment was carried out as follows. A model of formation water of the Usinsk field with an injection rate of 1 cm³ / min at 23 °C was filtered through a heterogeneous reservoir model in the “reservoir – well” direction until the product completely watered at the outlet of the model. Every 10-15 minutes, temperature, pressure at the inlet and outlet of the columns, the volumes of displaced oil and water from each column were measured. According to the obtained data, the pressure gradient grad P, atm / m, the filtration rate V, m / day, μm² / (MPa · s), and the oil-displacement’s coefficient Kv, %, were calculated. After oil was displaced by water in the “reservoir – well” direction, 0.5 pore volumes of the composition were pumped at 23 °C and 150 °C and model filtration of formation water through a heterogeneous reservoir continued. Measurement of the above parameters—temperature, pressure at the inlet and outlet, volumes of displaced oil and water from each column was carried out continuously (every 10-15 minutes).

3. Results and discussion

To conduct filtration tests, were prepared 3 models of a heterogeneous reservoir (Table 1). The gas permeability of the heterogeneous reservoir model was in the range from 0.343 to 2.100 μm². The permeability ratio within the model was from 1.5 : 1 to 4.1 : 1, and the initial oil saturation of the columns was from 60.31 to 88.94 %.

| Model | Gas permeability [μm²] | Permeability ratio of models | Initial oil saturation [%] |
|-------|------------------------|------------------------------|---------------------------|
| 1     | 0.500                  | 1.5:1                        | 63.83                     | 60.31         |
| 2     | 1.555                  | 4.1:1                        | 79.85                     | 71.05         |
| 3     | 2.100                  | 2.3:1                        | 72.65                     | 88.94         |

Figure 1 and table 2 show the results of filtration studies of a heterogeneous reservoir model consisting of two columns having a gas permeability of 0.343 to 2.100 μm². The experiment was
conducted as follows. Through a model of a heterogeneous reservoir of the Usinsky field at 23 °C, the model of produced water of the Usinsky field was filtered with a discharge rate of 1 cm³/min until the water cut at the output of the model was completely cut off. The oil-displacement’s coefficient for the first and second columns when pumping 4.8 pore volumes of the reservoir water model through the heterogeneous reservoir model was 44.1%.

Filtration was continued until the water cut content of the product was completely cut off from the model. The increase in the oil-displacement’s coefficient at 23 °C due to the use of the composition and subsequent filtration of the formation water model was 9.1 and 6.5 % for the first and second columns, respectively.

Then they raised the temperature to 150 °C, stood for 2 hours and continued pumping water. The fluid mobility and filtration rate in the columns increased. An increase in the temperature of the heterogeneous reservoir model to 150 °C followed by filtering of the reservoir water model of the Usinsky field through the heated heterogeneous reservoir model led to a further washing out of the residual oil and an increase in the oil displacement’s coefficient, which increased by 7.5 and 5.9 % for the first and second columns, respectively.

After filtering the stratal water model in the “well-reservoir” direction, the second AODC rim was pumped in a volume equal to 0.5 pore volume, which was pushed by the rim of the water. After thermostating for 20 hours at a temperature of 150 °C, the filtration of the stratal water model in the “reservoir-well” direction was resumed. Filtration was carried out until the water output at full output. The increase in the oil displacement coefficient due to the use of an oil displacing composition with subsequent filtration of the stratal water model for the first and second columns was 7.9 and 7.2 %, respectively.

**Figure 1.** Filtration characteristics of an inhomogeneous carbonate core material model with AODC treatment (initial gas permeability of the first and second columns is 0.500 and 0.343 μm²).
According to the results of the experiment, the total oil displacement’s coefficient for the first and second columns was 69.6 and 63.9 %, and the oil displacement’s coefficient due to the use of AODC was 25.5 and 19.82 %.

An analysis of the AODC components in the samples taken at the outlet of the heterogeneous reservoir model showed that the value of the hydrogen index during the experiment decreases from 6.9 to 6.3 pH units, and then, after heating to 150 °C and subsequent exposure, as a result of the hydrolysis of urea included in the composition of AODC is shifted to the region of alkaline values, reaching 9.2 pH units. The amount of urea in the samples of the selected water is 79.4 and 80.5 % of the initial content in the composition in the first and second columns, respectively, indicating a small degree of urea hydrolysis.

Filtration experiments 2 and 3 were carried out in a similar manner (table 2).

**Table 2. AODC Oil displacement test results.**

| № models experiment | № column | Gas permeability [μm²] | Mobility ratio | Oil-displacement coefficient [%] |
|---------------------|----------|------------------------|----------------|----------------------------------|
|                     |          |                        | Before injection of the composition | After injection of the composition | Water | Water and acid composition AODC at 23 °C (at 150 °C) / total |
| 1                   | 1        | 0.500                  | 46.1:1         | 1.5:1                            | 44.1  | 69.6 | 9.1 (7.5) /16.6 |
|                     | 2        | 0.343                  |                |                                  | 9.1   | 63.9 | 6.5 (6.0) /12.5 |
| 2                   | 1        | 1.555                  | 18.5:1         | 1.2:1                            | 15.1  | 69.4 | 5.7 (6.0) /24.3 |
|                     | 2        | 0.382                  |                |                                  | 5.7   | 38.1 | 9.2 (13.8) /11.7 |
| 3                   | 1        | 2.100                  | 1.95:1         | 2.4:1                            | 30.5  | 47.1 | 10.4 (6.1) /11.5 |
|                     | 2        | 1.200                  |                |                                  | 8.2   | 47.1 | 8.2 (3.3) /70.9  |

In all experiments performed, the alignment of filtration flows (fluid mobility in the columns) was observed. The increase in oil-displacement’s coefficient due to the use of AODC occurred both at low and at high temperature: the increase in oil-displacement’s coefficient for experiments 2 and 3 at a temperature of 23 °C is in the range of 5.7-10.4 %, at 150 °C - in the range of 6.0-13.8 %.

An analysis of the AODC components in water samples taken at the outlet of the heterogeneous reservoir model showed an increase in the pH value to a maximum of 8.6 pH units, while the pH values are determined by the hydrolysis of urea and depend on the temperature of the experiment, at low temperatures, the pH values were in the range of 5.6 to 7.0 pH units, at high - in the range of 8.4-8.6 pH units. The amount of urea in the samples of water taken according to the results of experiments 2 and 3 is 23.3 and 94.0 % of the initial concentration in the first and second columns, respectively, indicating a different degree of urea hydrolysis.

**4. Conclusion**

The filtration characteristics of heterogeneous reservoir models during oil displacement using the acid oil displacing composition AODC are investigated. As a result of the AODC composition processing the heterogeneous reservoir model, the acid components interact with the carbonate reservoir rock with an increase in permeability, which can lead to an increase in the injectivity of the heterogeneous reservoir model (wells). As a result of this interaction, carbon dioxide CO₂ is released. Due to the hydrolysis of urea, which is part of AODC, an alkaline system is formed at high temperature and carbon dioxide is also released. CO₂ dissolves in oil, reducing its viscosity, and contributes to its
displacement. A formed alkaline medium with a pH value of 8.4-8.6 pH units reduces the interfacial tension at the oil-water phase boundary and promotes the displacement of oil by a surfactant composition. As a result, the increase in the oil-displacement’s coefficient from the columns of the heterogeneous reservoir model was 5.7–10.4 % at a temperature of 23 °C and 6.0–13.8 % at 150 °C.

In addition, the analysis of water samples taken at the outlet of the heterogeneous reservoir model showed a high urea content of 79.4 and 94.0 %, which indicates a low degree of its hydrolysis. However, in a real reservoir, due to the longer residence time of the AODC composition in the reservoir conditions, one should expect a maximum degree of urea hydrolysis, and, consequently, an increase in the oil displacing effect from the use of the AODC composition.

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