Evaluation of Water-Alternating-Gas Efficiency when Using Wide Range of Gas Composition

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Abstract. There are two methods aimed at uniform displacement of oil without any gas breakthroughs. One of such methods is the replacement of gas with a mixture of gas and water, alternating the injection of water and gas rims and another one is the decrease in gas mobility, using foam. The article is devoted to the study of the first method. The object of the study was an area of Ach reservoir of the Vyintoiskoe oil field. To assess the influence of gas composition on the displacement process, modeling of the injection of a mixture of water with both dry and wet gases was carried out. The difference in the component composition of dry and wet gases was set by assigning different values of density and viscosity. With the help of the ECLIPSE 300 the gas density determines its interaction with the oil phase by simulating multicomponent gas. For both a single-layer and a two-layer model of an oil field the exploitation indices were obtained (for gas contents in the injected water-gas mixture of 0; 10; 25; 40; 50; 60; 90; 100 %). The use of wet gas in a mixture with water makes it possible to increase the final oil recovery factor (ORF) up to 68%, which is 4% higher compared to the value of this indicator when using water (64%). These results remain valid with the gas content up to 60%. The use of mixtures enriched with gas is impractical due to the early breakthrough of gas to the production well. In comparison with the water displacement, an earlier breakthrough of gas is observed when the gas content exceeds 10%. On the contrary, when the gas content is 10%, a later breakthrough is observed. For this type of collector it is recommended to apply the mixture with gas content of 10% to achieve the optimum effect.

1. Introduction

Currently, in order to maintain the production of hydrocarbons, a field exploitation of hard-to-recover reserves as well as methods aimed at oil recovery increase are applied; besides, shelf deposits are being developed. The methods are being studied and experience of their application is being expanded [1-5]. The methods aimed at oil recovery increase are favored by the availability of ready-made infrastructure, and, therefore, relatively small investments for additional research [6], preparation and injection of reagents and more detailed monitoring of the process. The disadvantages of these methods include the problems associated with the need to organize the production, cleaning and dosing of chemicals, as well as relatively low degree of study and adaptation of methods [7, 8].

The main drawback of oil displacement due to gas injection is the formation of an unstable displacement front for a given process. In addition, before designing the actions for water and gas
influence, it is necessary to evaluate the capacity of gas sources planned for injection and determine whether it has enough reserves for a successful implementation of the process [9]. During the evaluation it is necessary to find an effective ratio of injected water and gas. Such estimates were made in the works of a number of authors [10, 11].

2. Objective
The objective is to study gas replacement method with a mixture of gas and water, by alternating injection of water and gas rims to achieve uniform displacement without gas breakthroughs.

3. Methods and materials
Table 1 shows a brief geological and physical description of the selected area of Ach site in the Vyintoiskoe oil field.

| Reservoir | Ach$_1^1$ | Ach$_1^2$ | Ach$_2^1$ | Ach$_2^2$ | Ach$_3^{1-1}$ | Ach$_3^{1-2}$ |
|-----------|-----------|-----------|-----------|-----------|--------------|--------------|
| Depth, m  | 2824-2877 | 2884      | 2897      |           |              |              |
| Number of permeable intervals | 1.0 | 3.8 | 3.0 | 1.3 | 6.9 | 1.0 |
| Average effective net oil thickness, m | 0.6 | 4.3 | 1.9 | 2.4 | 3.7 | 1.5 |
| $P_{pl}$, MPa | 2.96 | 2.94 | 2.98 |
| $P_{pump}$, MPa | 1.16 |
| $T_{pl}$, °C | 92 | 97 | 96 |
| Oil density, kg/m$^3$ | 819 |

Due to low reserves of the dissolved gas, a gas injection from the Povkhovskoye oil field was arranged the component composition of which is given in Table. 2.

| Name               | mole, % |
|--------------------|---------|
| carbon dioxide     | 0.212   |
| nitrogen+rare      | 0.823   |
| methane            | 74.99   |
| ethane             | 8.33    |
| propane            | 9.05    |
| isobutane          | 1.55    |
| norm. butane       | 2.87    |
| isopentane         | 0.49    |
| norm. pentane      | 0.66    |
| hexanes            | 0.33    |
| Molecular number   | 23.2    |
4. Results
The Eclipse E300 (blackoil mode) was used to carry out the study. A square-shaped reservoir has geometrical dimensions of 500x500x(35.5 + 58.1) m. Its properties are described by the model representing a square and 50x50x2 cells with boundary conditions of non-permeability on the faces. The reservoir consists of two layers with 2,500 cells each with different absolute permeability in x and y (2 mD is a top layer, 1 mD is a lower one) and involves studying the influence of gravity segregation of fluids on the displacement process. The remaining parameters are assumed to be the same for both layers (porosity is 0.16; sandiness is 0.342; the depth of the upper face of the first layer of cells is 2,831 m; the initial reservoir pressure is 30 MPa; the depth of gas-liquid contact is 2,924.6 m; the depth of oil-water contact is 2,831 m). All grid cells are initially saturated with oil. Both mining and injection wells are located in the opposite corners of the square.

Under the water-gas influence, the residual oil saturation with respect to Sorg gas is much less than in Sorw water and comprises about 0.1 versus 0.3. Thus the displacement of oil by gas reduces the capillary forces resulting in the retention of the residual oil ganglia [12]. On the other hand, the use of gas increases the ratio of the displacing to the displaced fluids due to the low gas viscosity. A low ratio of mobilities leads to an unstable mode of displacement [13] and a loss of control over the process.

The combined use of water and gas leads to a decrease in the mobility of both water and gas in a porous medium and makes it possible to control the stability of the displacement front due to a change in the ratio of the injected water and gas.

A three-phase filtration model was adopted; oil, gas and water were selected as active phases. A scale option of the end points of saturation tables was activated. An immiscible displacement mode was set in the model. The initial data for the saturation and phase permeability tables are shown in Fig. 1.
Figure 1. Relative permeability in the system: a) oil - water; b) oil - gas

Stone models are widely used for phase permeability plotting in the oil-gas-water system [10, 11]. An algorithm for plotting the relative phase permeability curves assumes that only two mobile phases can exist in each pore canal at a given time. In a hydrophilic porous medium, it would be a wetting phase when water contacts with gas and oil; when gas is in contact with water and oil it would be a non-wetting phase. It is assumed that the phase permeability for these fluids is determined only by the rate...
of their own saturation. Oil in such an environment shows different wettability with respect to water and gas, therefore, it depends on water and gas saturation.

To evaluate the influence of gas composition on the displacement process, the simulation of injection of a mixture of water with both dry and wet gases was carried out. The difference in the component composition of dry and wet gases was set by assigning different values of density and viscosity. In the ECLIPSE 300 program used, the gas density determines its interaction with the oil phase by simulating a multicomponent gas. The surface condition density is 819; 1.023; 0.939 kg/m$^3$, respectively, for oil, water and wet gas. The viscosity is assumed to be 0.495; 0.5; 0.0254 cP, respectively, for oil, water, dry gas and wet gas.

For the production well a bottom-hole pressure of 27 MPa is set as the target and the injection is controlled by the consumption of gas-liquid mixture in the reservoir conditions assumed to be 20 m$^3$/day. The injection of the displacement mixture is performed by alternating injection of water and gas. Variation in gas and water rim size (gas-water ratio) was accomplished by varying the injection period of each fluid. The maximum continuous flow period of the fluid ranges from 5 to 45 days. Both for a single-layer and for a two-layer model of the deposit, exploitation indices were obtained for gas contents in the injected water-gas mixture of 0; 10; 25; 40; 50; 60; 90; 100 %. Thus, the study allows us to compare the efficiency of oil displacement by means of different composition of water and gas mixtures, as well as clean water and gas.

The oil recovery factor is used as an evaluation parameter for efficiency assessment. Traditionally, the injection of 2-3 pore volumes of reagent is analyzed. Therefore, the study period is limited to the moment of pumping into the injection well of four pore volumes under the reservoir conditions. Further in the text the term “final ORF” will have a meaning of the ORF at the time of injection of four pore volumes.

As a result of simulation, a number of oil saturation indices were obtained and displayed in the form of diagrams in Fig. 2. The diagrams denote the time of injection of 0.23 pore volume for different fluid ratios in the injected mixture. Two frontiers of displacement are distinctly distinguished: blue, corresponding to the displacement by water; and orange, corresponding to gas.

![Figure 2. Distribution of oil saturation when injecting a mixture of water and wet gas for gas-water ratio (left-to-right) equal to 0; 10; 25; 40; 50; 60; 90; 100% with 0.1 pore volume at the time of injection. Top row - top view, top layer; bottom row - bottom view, bottom layer. Two-layer model.](image-url)

The breakthrough of injected gas to the production well is already observed at 25% of gas content in the injected mixture. The most effective mode should correspond to the case when the fronts are at a minimum distance from each other. The coincidence of the fronts in a lower low permeability layer is noted only when the gas content is 10%. At the same time, in the upper layer there is no coincidence, the front of displacement by gas is observed at any gas content. With an increase in the proportion of gas in the injected mixture, the efficiency of oil displacement from the lower layer with low
permeability decreases. At the same time the decrease in the oil saturation of the upper layer cells is clearly noticeable due to their intensive saturation with the injected gas. Thus, one can talk about the gravitational separation of injected mixture components in the reservoir.

Fig. 3-4 shows the ORF and injection volume curve. The dependence is linear until the mixture breaks into the injected well. Obviously, the best option is when the breakthrough (this corresponds to a change in the slope of the curve) occurs later and the final value of ORF is higher.

**Figure 3.** Dependence of oil recovery rate on the injected reagents volume expressed in pore volumes for different ratios of wet gas and water.
Figure 4. Dependence of oil recovery rate on the injected reagents volume expressed in pore volumes for different ratios of wet gas and water. Enlarged representation.

Wet gas application blended with water makes it possible to increase the final ORF up to 68% which exceeds the value of this index by 4% when using water (64%). These results remain valid with the gas content up to 60%. The use of mixtures rich with gas is impractical due to the early gas breakthrough to the production well. In comparison with water displacement, an earlier breakthrough of gas is observed at a gas content exceeding 10%. At a gas content of 10%, on the contrary, a later breakthrough was noted. To achieve an optimum effect, a mixture with a gas content of 10% is recommended for this type of collector.

5. Conclusions
In the course of the study, a dependence of the efficiency of water-gas influence on the gas composition was established. With a larger content of intermediate components in the injected gas, the displacement process is more efficient, which is associated with the lower mobility of a wet gas in the reservoir compared with the dry one.

The process of water-gas exposure is most effective when the water and oil fronts coincide.

The hypothesis on the positive effect of gravitational phase separation in a non-uniform vertical formation has been confirmed. For reservoirs of this type, it is advisable to use a water-gas effect using a mixture of water and 10% of a wet gas ratio.

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