WP4-1

Justification of the Selection of Oil Displacement Agents for Development of Oil/Gas/Condensate Fields in Eastern Siberia on the Basis of Experimental Study Results

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SUMMARY

Complex experimental studies on physical modeling of processes of oil recovery from oil rims using the various innovation technologies and displacement agents are required for efficient development of oil/gas/condensate fields.

The present report discusses the selection of the most optimum technology of oil recovery during development of the oil rim in the Botuobinsky horizon of the Chayandinskoye oil/gas/condensate field (Chayanda OGCF) located in Eastern Siberia. A combination of laboratory experiments on oil displacement with various agents form the basis of the work. Nitrogen, carbon dioxide, separation gas, water and polyacrylamide (PAA) water solutions are proposed for comparison as such agents.

Anomalous thermobaric modes of hydrocarbon occurrence in the Chayanda OGCF (reservoir temperature 9-13 ^{o}C, reservoir pressure – 13.2 MPa) did not allow to perform physical modeling of filtration and displacement processes in formation conditions until now.

In the present work the experimental studies of filtration characteristics of formation core models have been carried out using the modern precise equipment (double and three-phase filtration units of Temco and TerraTek production, computer tomograph Tomoscan 60/TX). They allow to propose a methodological approach to selection and sound use of displacement agents for improvement of the oil recovery factor for the Chayanda OGCF.

ROUTINE OF THE EXPERIMENT

The method envisions the determination of completeness of oil recovery, an individual or composite rock specimen is oil saturated at the expense of filtering of the displacement agent until practically complete termination of oil recovery from the simulated formation. A special filtration unit is used to determine the oil displacement factor [1-3]. The function block diagram of the filtering unit is given in figure 1. Its properties are shown in table 1.

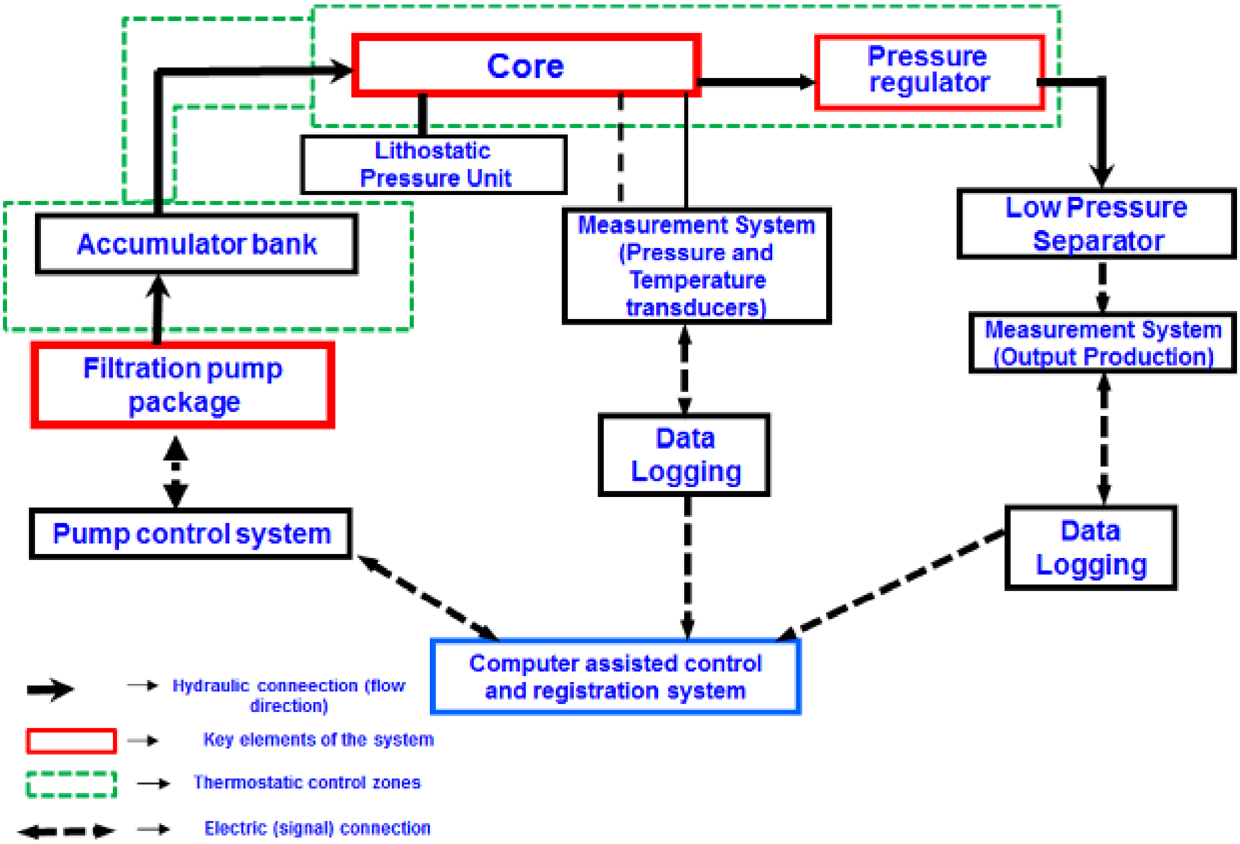

Figure 1 - Function block diagram of two-phase filtering unit

GENERAL CHARACTERISTIC OF EXPERIMENTAL UNIT

The main elements of the measuring equipment are: the mechanical system based on precision pumps injecting fluids into the sample at formation pressure in various proportions at the constant flow rate, Hassler type or hydrostatic core holder (Fig. 2), containers for feeding of fluids and gases, system of measurement of volumes of outgoing fluids, thermostatic regulation system, data control, monitoring and registration system (Fig.3), the pressure drop measurement system can be used as an auxiliary one. Filtration system can be equipped with the complementary unit for measurement of the current saturation – computer tomograph or x-ray saturation scanner (Fig.4).

To provide the maintaining of formation temperatures of Chayanda field the unit is equipped with thermostat, ensuring constant thermostatic control of the system at abnormally low formation temperature.

Table 1 - Process parameters of two-phase filtration unit

Parameter	Two-phase filtration unit
Formation pressure, MPa	up to 70
Rock (lithostatic) pressure, MPa	up to 70
Working temperature, °C	up to 150
Fluid rate in a core, m/day	0,10 – 255
Range of set flow rates at filtration, cm^3/min	0,00001 - 25
Accuracy of flow rate maintaining by pumps, % from set value	~ 0.3
Core length (core holder characteristic)	up to 30 cm, up to 50 cm, up to 1 m
Core diameter, m	0.03

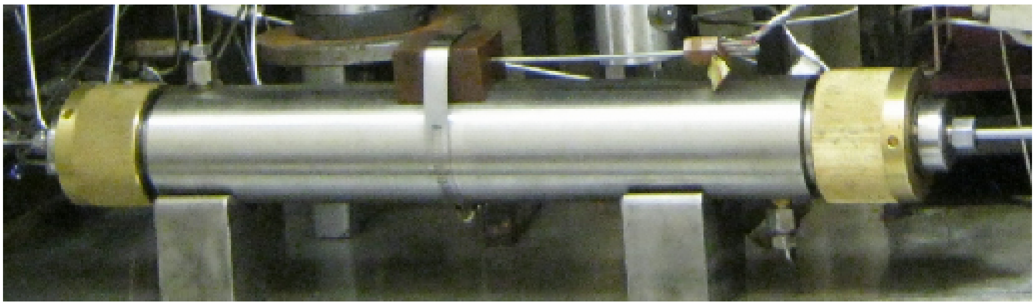

Figure 2 – Core holder of hydrostatic type

Figure 3 – General view of control cabinet (left) and filtering unit (within thermostatic box, right)

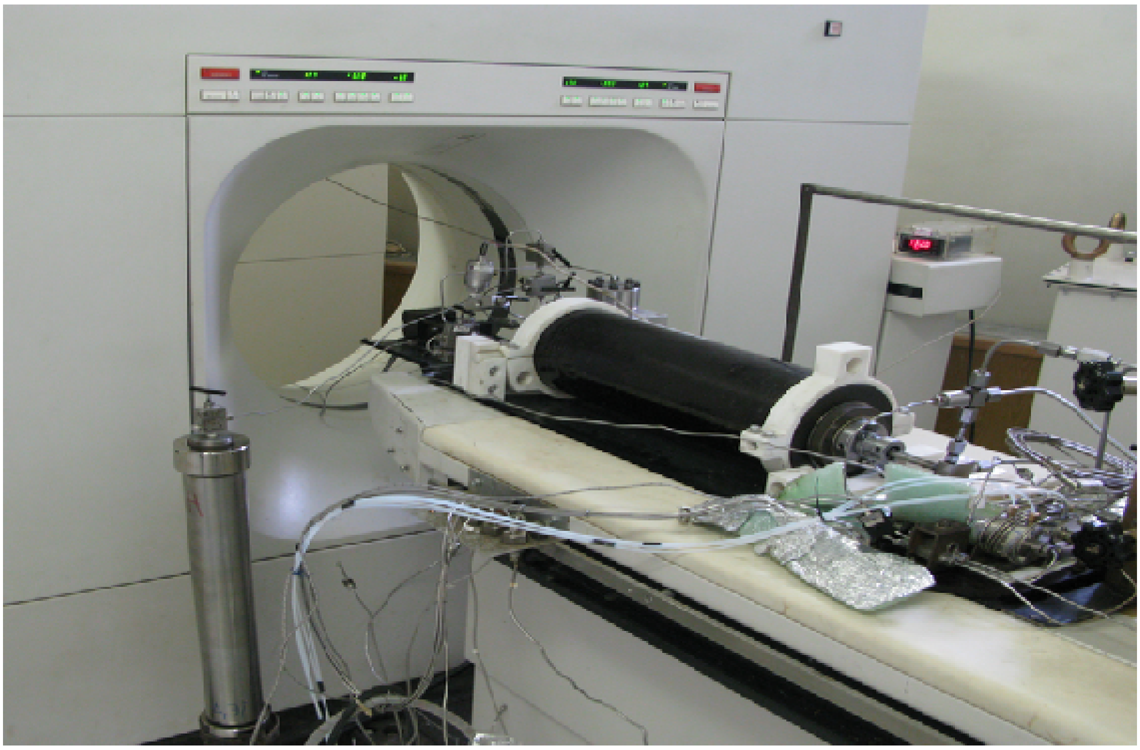

Figure 4 - General view of computer tomography setup

PREPARATION OF CORE MATERIAL, FLUIDAL SYSTEM AND PROCEDURE OF STUDIES

The source core material are cylindrical samples, drilled in parallel to bedding, of correct form, with the length about 3-5 cm and diameter about 3 cm.

Before measurements the samples are subjected to extraction by alcohol and benzene mixture (proportion of components 1:3) for removal of hydrocarbons, with further drying down to the constant mass at the temperature t = 102-105 ^{o}C. The composite sample is formed in accordance with the values of absolute permeability to gas, measured on each individual sample. The compositing procedure is selected so that along the direction of oil displacement each subsequent sample had smaller permeability.

Characteristics of formation models are shown in Table 2, models photos can be viewed in Figure 5.

For experiments the recombined oil sample (ROS) based sampling of oil of Chayanda OGCF. Recombined oil has been formed by careful stirring of degased ("dead") oil and modelled separator gas of Chayanda OGCF in a special PVT vessel at formation conditions. Meanwhile the modern equipment and PVT cells of the company Chandler Engineering, model 3000-GL PVT system have been used.

Table 2 - Characteristics of formation models

Model No.	Permeability to gas, k_{N2}, mD	V_{pore}, cm^3	Length, cm	Diameter, cm	Porosity, %	S_{BO}, %
No. 1 (“200 mD”)	196.6	15.12	17.80	3.009	11.90	0.00
No. 2 (“700 mD”)	727.1	16.85	21.80	2.983	11.04	0.00
No. 3 (“1650 mD”)	1659.89	44.00	29.91	2.974	21.18	0.00
No. 4 (“1140 mD”)	1139.75	12.15	9.135	2.967	19.24	29.97
No. 5	241.3	7.19	5.96	2.940	17.85	1.01
No. 6	345.7	7.00	5.975	2.950	17.35	1.94
No. 7	82.5	4.97	5.92	2.953	12.35	0.95


Group 200 mD

Group 700 mD

Group 1650 mD

Figure 5 - Formation models – composite core samples

After evacuation of the formation model it is filled by kerosene by means of its filtering in amount of 3-5 pore volumes with simultaneous pressure increase in the system up to formation one, then the kerosene is replaced by oil (recombined sample), meanwhile the model is filtered by at least 5 pore volumes of oil.

The experiment start from the moment of starting of the measurement pump feeding the displacement agent into the formation model. The fluid is fed at a constant volume flow rate selected according to anticipated water filtration rates at accepted system of development of Chayanda OGCF.

The peripheral speed at tests with oil displacement by the agent, as a rule, does not exceed 2 m/day. In the present work the accepted v (corresponding to peripheral speed of the agent injection rate ~1 m/day) have amounted from 0,04 up to 0,06 cm^3/min. The agent injection at the selected rate takes place up to maximum possible oil displacement from the formation model corresponding to injection of minimum 3-5 volumes of pores of voids.

The following procedure of displacement factor determination is accepted: the amount of outgone oil is measured at room conditions, the amount of oil at formation conditions is recalculated, additionally the amount of oil in delivering tubes and "dead" volumes of the system is calculated, then the oil saturation of the pore space of the model as of the moment of the experiment completion is calculated. Knowing the initial and final pore volume of the model, filled with oil, it is possible to calculate the oil displacement factor (by the respective agent).

CALCULATION FORMULAS FOR FINDING K_{displ}

$$V_{oil} = \theta \cdot V_{o\_lab}\ , \tag{1}$$

where V_{oil} – oil volume at formation conditions; V_{o_lab} – oil volume at room conditions; θ – volume coefficient.

$$K_{displ} = \frac{V_{oil}}{V_{pore} - V_{wres}}\ , \tag{2}$$

where K_{displ} – oil displacement factor; V_{pore} – pore volume; V_{wres} – residual water volume at formation conditions.

And the relative error will be found:

$$\frac{\Delta K_{displ}}{K_{displ}} = \frac{\Delta V_{oil}}{V_{oil}} + \frac{\Delta V_{pore}}{V_{pore}} + \frac{\Delta V_{wres}}{V_{wres}} \tag{3}$$

CRITERIA OF LIKELIHOOD OF MODELLED AND REAL SYSTEMS

The main experiment has been performed at thermobaric conditions applicable to formation conditions of Botuobinsky horizon of Chayanda OGCF: $P_{formation}$=13,2 MPa, $T_{formation}$=11,0 °C, P_{conf}=35 MPa.

For correct simulation of displacement processes occurring in the formation, it is very important to follow the likelihood criteria: it is necessary to observe the likelihood of modeling conditions with the real conditions of formation occu

In the experiment the pressure drop in the composite model of the formation has been set as 20 kPa minimum, and the lengths of formation models have exceeded L_{min}, that is, the criteria of likelihood of modeled experiment and real filtering in the formation have been completely observed.

$$\pi_1 = \frac{\Delta P_{кап}}{\Delta P} = \frac{\sigma}{\Delta P \sqrt{\frac{k}{m}}} \qquad \pi_1 \leq 0,5 \qquad (4)$$

$$\pi_2 = \frac{grad(P_{кап})}{gradP} = \frac{\sigma}{k\left|gradP\right|} \qquad \pi_2 \geq 0.5 \cdot 10^6 \qquad (5)$$

MAIN RESULTS AND THE DISCUSSION

The oil displacement by carbon dioxide and nitrogen

Behavior of curves of the oil displacement by carbon dioxide considerably differ from the curves of displacement by nitrogen (Fig. 6). The main differences can be formulated as follows:

- The value of oil displacement factor (by carbon dioxide) is much greater, than for oil displacement by nitrogen;
- at oil displacement by nitrogen the maximum displacement factor is registered at the reservoir from the group of permeabilities “700 mD”, while for oil displacement by carbon dioxide in the same reservoir the minimum K_{dis};
- values of oil displacement factors (by carbon dioxide) for various groups of permeabilities are close, and maximum displacement factor is registered on the best reservoir with the permeability “1650 mD”;
- oil displacement by both carbon dioxide, and nitrogen is of "piston" nature for all groups of reservoirs. However, for the case of oil displacement by carbon dioxide this process is longer by time and the breakthrough of the displacement agent start near 0.5-0.6 of pore volumes of injected agent.

The oil displacement by water

Different results of the oil displacement by water for variety of core models with different permeabilities are presented in Fig. 7. It can be seen from the figure that displacement factor mean value for all Chayanda permeabilities groups is less than 0.5. For comparison, the same figure placed literature data on water displacement factor obtained from reservoir models of Sredne-Botuobinskoye oil-gas-condensate field.

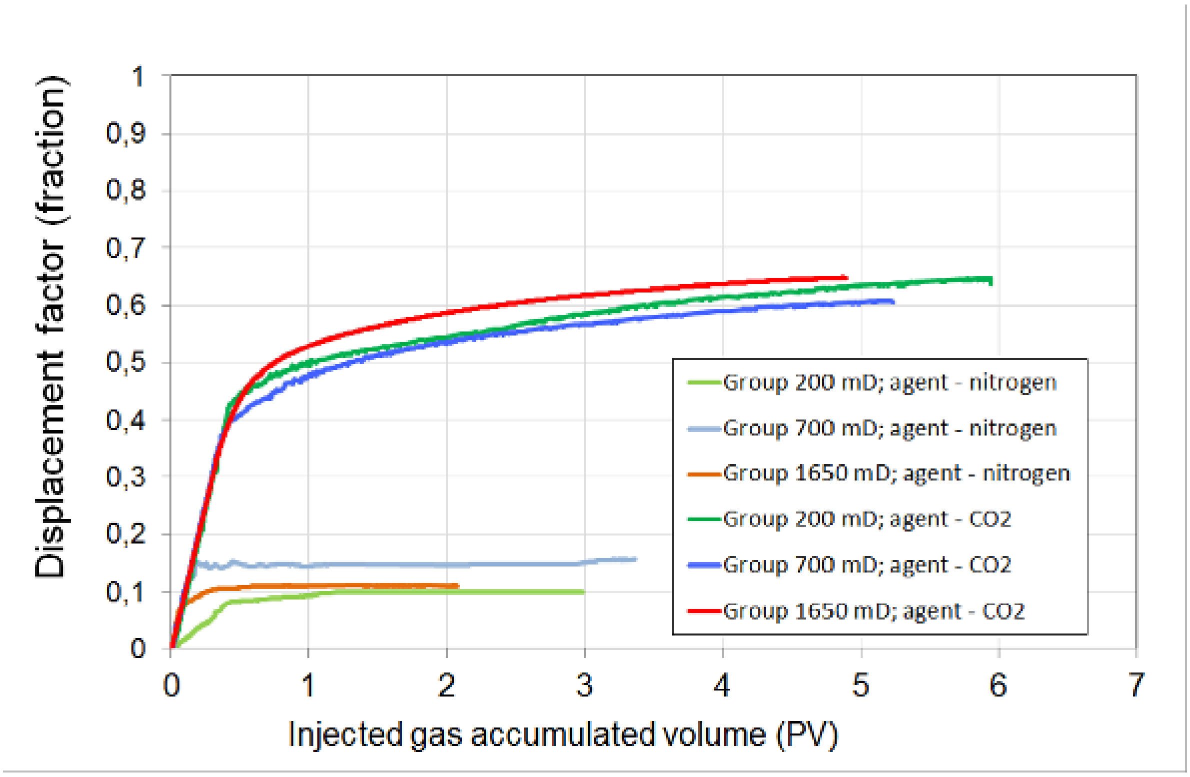

Figure 6 – Curves of oil displacement factor versus injected volume of nitrogen and carbon dioxide for the models of the formation No. 1-3 of Chayanda OGCF

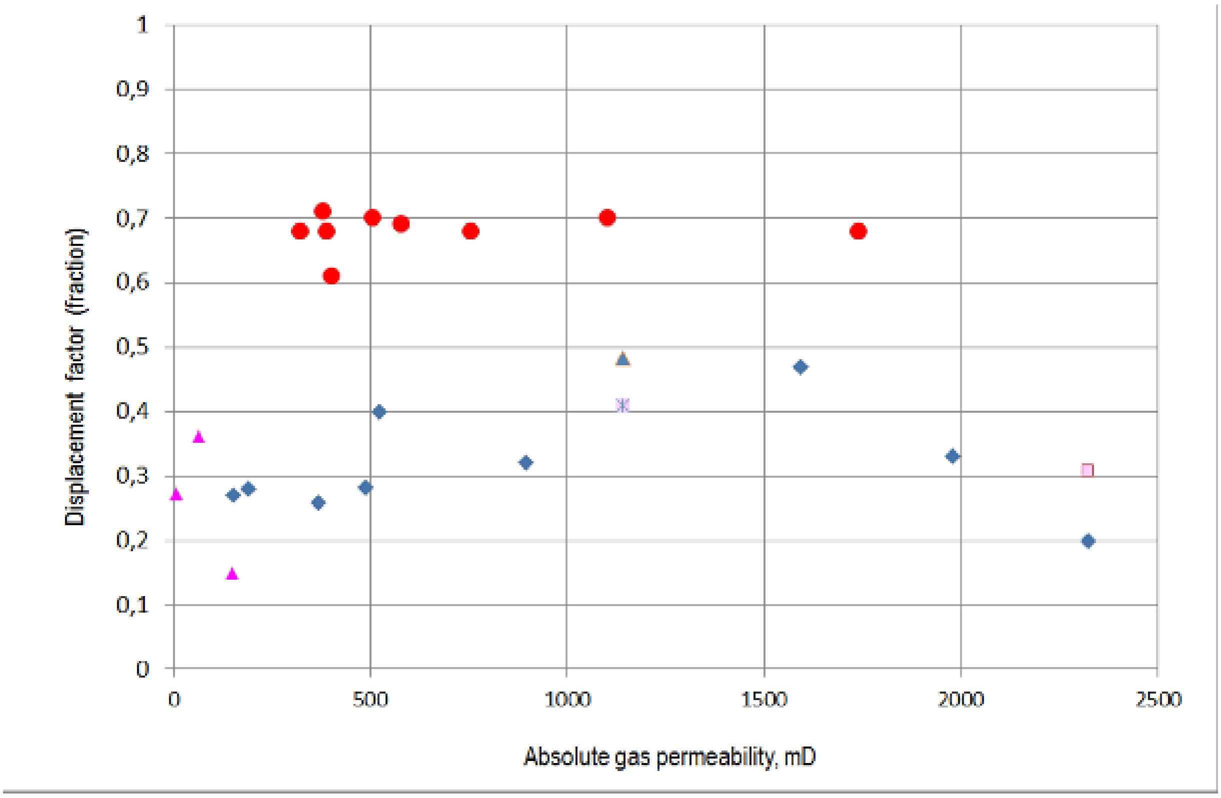

Figure 7 - Curve of oil displacement factor (by water) versus absolute permeability of formation models: red dots - Sredne-Botuobinskoye OGCF, dark-blue dots - Chayanda OGCF

The oil displacement by PAA solution

In Fig. 7 has been shown also the oil displacement by PAA solution ("star sign") for model 4. As shown in Fig. 7 and Table 3 the PAA solution is not strong increase the coefficient of oil displacement.

Table 3 - Comprehensive representation of results of experiments with oil displacement by PAA solution (model 4)

Displacement agent	Oil saturation, %		K_{dis},	Peripheral injection rate,
	initial	final	%	m/day
PAA solution	70.03	40.96	41.51	1.0
Additional displacement by formation water at different injection rates	40.96	40.86	41.61	1.0
	40.86	40.86	41.61	3.0
	40.86	40.86	41.61	6.0
	40.86	36.23	48.26	12.0

0,2% PAA solution which demonstrates more stability in properties and high value of share viscosity (appr. 8,73 mPa·s) was used. In table 4 viscosities of formation water, PAA solution and recombined oil are shown.

Table 4 – Fluid viscosity values at reservoir conditions

Fluid	Viscosity, MPa s
Formation water	4.2
PAA solution	8.73
Recombined oil	12.35

The oil displacement by separation gas

Results of oil displacement factors by separation gas are shown in table 5.

Table 5 – Final values of oil displacement factors (by separation gas) for the models of formation of Chayanda OGCF

Formation models	Model permeability by gas, mD	Displacement factor, %
Model 5	241.3	16.7
Model 6	345.7	25.42
Model 7	82.5	20.41

From the table 5 it can be seen that final displacement factor for models 5-7 is less than 26%. Maximal displacement factor by separation gas (K_{displ}= 25,42%) was obtained for model 6 with highest value of absolute gas permeability.

RESULTS OF ANALYSIS

On the basis of experimental studies performed using 7 models of formation of Botuobinsky horizon of Chayanda OGCF, it has been established, that the most efficient oil displacement agent, among nitrogen, CO_2, formation water, PAA solutions, and also the separator gas, is the carbon dioxide, at the formation conditions ($P_{formation}$=13,2 MPa, $T_{fornation}$=11,0 ^{0}C, P_{conf}=35 MPa) in liquid state.

CONCLUSIONS

1) The methodical aspects of conducting of qualitative experimental studies for determination of oil displacement factor by the various agents have been worked-out in details: by nitrogen, carbon dioxide, formation water, PAA water solutions, and also separator gas using the formation models formed from core material of Botuobinsky horizon of Chayanda OGCF.

2) The analysis of results of determination of factor of oil displacement by the active agents at formation conditions ($P_{formation}$=13,2 MPa, $T_{formation}$=11,0 ^{0}C, P_{conf}=35 MPa) has shown, that if the factor of oil displacement by water from the formation models of Chayanda OGCF does not exceed 40 %, at oil displacement by PAA water solution it is possible to displace more than 41 % of oil. Besides the additional oil displacement by formation water at injection rates from 1 up to 6 m/day practically has no effect to final displacement factor, and at injection rate of formation water 12 m/day the significant increase of displacement factor (up to 48,3 %) is observed.

3) For formation conditions of Botuobinsky horizon of Chayanda OGCF the most efficient oil displacement agent, among nitrogen, formation water, PAA water solutions, and also separator gas, is carbon dioxide, which allows to displace up to 65 % oil contained in the oil formation model.

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