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PROSPECTS FOR IMPROVING THE EFFICIENCY OF WATER INSULATION WORKS IN GAS WELLS

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ABSTRACT

In the oil industry, the inflow of water into the gas and oil wells represents always an important issue that needs to deal with. In this study a water-repellent composition, which is based on volatile hydrocarbon solvent, was proposed for handling of water isolating work in gas wells. As a volatile hydrocarbon solvent, it was quite promising to use gas condensate and its primary processing products (like stable gas condensate SC and light distillate of gas condensate DGCL). Initially, we studied the effect of compositions based on the ABR water repellent, M100 fuel oil and solvents SC, DGCL and mixed in equal volumes of DGCL + SC on gas permeability of gas-saturated porous medium. The article presents the results of studies, conducted on physical models of the formation, confirming the efficiency and selectivity of the water-repellent composition impact on the water-cut interval.

Keywords: Gas wells, Permeability, Porous medium, Solvents, Resistance factor, Water repellent.

I. INTRODUCTION

A large number of reagents and compositions have been proposed for water insulation works. Especially extensive experience in the use of water-insulating compounds may find in the Russian oil industry. The experience of using water-insulating compounds in the oil industry is described and summarized in many works [1-3]. The most promising way to deal with inflow of water into the gas or oil well is the selective water isolation. It is possible to carry out selective water isolation if at least one of the following conditions is performed: water-isolating composition that acts almost exclusively in water saturated intervals; plugging water-insulating mass is formed almost only in water-saturated intervals; water-isolating composition and plugging water-insulating mass can be easily removed by oil or gas and are not washed away by water. It is quite difficult to select such materials, so there are few proposed methods of selective water-isolation. Characteristically, most studies do not distinguish between selective water-isolation and simply describe methods of water-isolation. For example, the detailed review “Analysis of literature and patent sources on technologies for selective isolation of water and elimination of behind-the-casing flows” [2] describes mainly the methods and reagents for creating insulating screens, and not the methods that meet the requirements of selective water-isolation [2].

According to the concepts of reservoir physics, a change in the wettability (hydro repellency) of the hydrophilic rock of the formation will slow down the rise of water in the bottom-hole zone of the gas formation [4].

Many reagents and compositions have been proposed for water insulation purpose.

The waste hydrocarbons are recommended as a water repellent for the water isolation in the bottom-hole formation [5,6]. Organosilicon compounds are also recommended as a water repellent (product 119-204, VTS-2, extract -700, etc.) [7-9]. In order for the water isolation method to be effective, the composition injected into the bottom-hole zone should not affect the gas permeability of gas-saturated interlayers and reduce the water permeability of waterlogged interlayers. Moreover, it is desirable that the water-repellent composition, when injected, to a greater extent enters the water-cut intervals, and not into the gas-saturated zones of the formation. [10]. This explains the selectivity factor that we tried to achieve under the current research using the solutions of water repellents with the low boiling solvents.

II. EXPERIMENTAL WORK

The main idea of this work was to use solutions of water repellents in highly volatile solvents. Actually, it is possible to achieve the removal of the water-insulating composition (liquid) from the productive gas-saturated layers by using a low-boiling solvent, the partial pressure of the components of which in the extracted gas is below the equilibrium pressure at the reservoir temperature [11,12]. This approach is most promising for Cenomanian gas deposits containing almost pure methane.

For the study, we used compositions containing a water repellent ABR (JSC "Chimeco-gang" TU 2483-081-17197708-03), fuel (heating) oil M100 and low-viscosity volatile hydrocarbon solvent (petroleum ether (PE), stable condensate (SC) and light distillate of gas condensate (DGCL)). For experiments, we used bulk porous media from the core of productive horizons of the Cenomanian formation, which were saturated with a model of the water of the Cenomanian horizon (density 1012 kg / m3). Part of water saturated reservoir models used to simulate gas-saturated porous medium. For this, air was blown through the reservoir model at a constant pressure drop (0.05 MPa). The model was placed vertically, and the gas (air) was supplied from above. Periodically, the direction of the gas flow was

changed (the model was inverted), which provided a more uniform distribution of residual water over the porous medium. The two-layer reservoir models consisted of gas-and water-saturated interlayers.

Flow experiments technique

Solutions of the composition were injected into horizontally arranged gas-and water-saturated reservoir models and left alone for a period of not less than 12 hours.

Water has been flowed through water-saturated reservoir models to determine the effect of the water repellent solution on the water permeability of the porous medium. In gas-saturated models, after injection of the composition, gas (air) was supplied from above into vertically located reservoir models at a constant pressure drop (0.05 MPa). The direction of injection of the water repellent solution and the direction of movement of water and gas have always been the opposite (the composition was pumped through the output of the reservoir models). Flow of liquids was carried out at a constant speed of about 3 m/day; the temperature of the experiment was 20–22^{o}C.

The following indicators were used to characterize the action of the water repellant solution.

a- Resistance factor (R) for characterizing the degree of reduction in the water permeability of porous medium.

$$R = \frac{\left(Q_1 / \Delta P_1 \right)}{\left(Q_i / \Delta P_i \right)}$$

Where Q_1 and ΔP_1 are, respectively, the volumetric flow rate and pressure drop during steady-state water flow in stage 1 (primary water injection); Q_i and P_i - respectively, the current flow rate and pressure drop during flow of water or composition.

In case of steady flow,

$$R_{res} = \frac{K_1}{K_2}$$

Where Rres is the residual resistance factor; k_1 and k_2 are, respectively, the water permeability of the reservoir model before and after injection of the composition.

Maximum resistance factor R_{max} and R_{res} characterize, respectively, the maximum and a steady state reduction in the water permeability of a porous medium.

b- The degree of water insulation (A,%) to characterize the level of reduction of water intake as a result of the action of the composition

$$A = \frac{100(K_1 - K_2)}{K_1} = 100(R-1)/R$$

c- The degree of restoration of gas permeability (B,%) of gas-saturated porous medium

$$B = 100\left({}^{K_{g2}}\!/_{K_{g1}}\right)$$

Where K_{g2} is the gas permeability of the reservoir model after injection of the composition; K_{g1} is the gas permeability of the reservoir model with residual water.

To determine the selectivity of the composition injection in experiments on a two-layer reservoir model, the ratio of the volume of liquid flowed through a water saturated interlayer to the volume of liquid flowed through a gas-saturated interlayer (Q_{water} / Q_{gas}) was used.

The time of 100% gas permeability recovery of gas-saturated porous medium (t100%) was estimated by the dynamics of permeability recovery of porous medium.

According to the results of the experiments, the influence of hydrocarbon solution of a water repellent on the water permeability of water-saturated porous medium was determined. It was observed that injection of a hydrocarbon liquid (PE and water-repellent solutions in PE) into a water-saturated hydrophilic porous medium is accompanied by a slight increase in pressure drop and resistance factor (Fig. 1, Table 1).

After switching to water injection (after composition), the pressure drop and resistance factor continue to increase and reach maximum values, after which they decrease. However, the initial water permeability is not restored, and the higher the concentration of the water repellent, the higher the residual resistance factors (see Table 1). Injection of PE provides a degree of water isolation equal to 62.5%, which is not enough to reduce significantly the flow of water into the wellbore. Water-repellent solutions with a concentration of 25 g / l and higher show a significantly higher water-insulating effect (A = 82.1–97.2%).

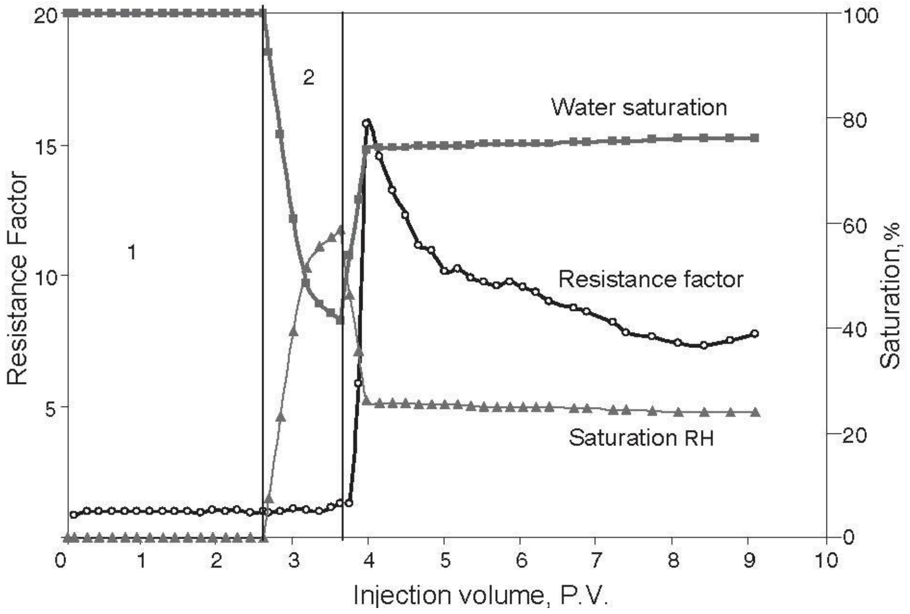

Figure 1: The dynamics of flow in experiment 8: 1 - water flow,

2 - injection of a solution of 25 g / l water repellent in PE.

The maximum and residual resistance factors exponentially depend on the concentration of the water repellent (Fig. 2). Such a strong influence of the concentration of the water repellent on the resistance factors indicates a change in the wettability of the porous medium (from hydrophilic to hydrophobic) and, as a consequence, a significant decrease in the phase permeability for water. The permeability of the porous medium does not significantly affect the injection results of the composition. The change in the permeability of the porous medium from 0.261 to 1.55 μm2 (i.e. almost 6 times) is not accompanied by a noticeable change in the degree of water isolation (82.1-86.8%), maximum and residual resistance factors (see table. 1).

Table 1. The effect of ABR concentration and permeability of reservoir models on the degree of water-isolation

Experiment	Gas Permeability, μm²	The concentration of water repellent, g/1l solvent	Resistance factor (When Injection a composition)		Resistance factor(When water flowing after composition)		The degree of water Isolating, %
			Maximum	After injection 1p.v. composition	Maximum	Residual	
Water repellent composition, a solution of ABR in PE							
4	0,466	0	1,46	1,12	2,85	2,67	62,5
7	0,662	5	1,46	1,0	2,83	2,06	51
15	0,261	25	1,17	1,17	10,9	5,6	82,1
8	0,615	25	1,30	1,30	15,8	7,6	86,8
11	1,55	25	0,96	0,96	14,5	5,7	82,5
6	0,490	52,6	1,9	1,9	68	35,4	97,2
Water repellent composition, ABR solution in a mixture of fuel oil M100(20% vol) and PE(80%)							
39	0,770	25	1,56	1,12	42,5	24	95,8

Influence of a hydrocarbon solution of a water repellent on gas permeability of gas-saturated porous medium

Injection of PE and water-repellent solutions usually occurs with a slight increase in pressure drop (Fig. 3, Table 2). The subsequent blowing of the water repellent solution with gas and the restoration of the initial gas permeability of the porous medium occurred quite quickly (Fig. 4, Table. 2). At the same time, the degree of permeability recovery in most experiments is higher than 100% (i.e., the gas permeability increases in comparison with the permeability before injection of the composition) and practically does not depend on the concentration of ABR Nephtenol (see table. 2).

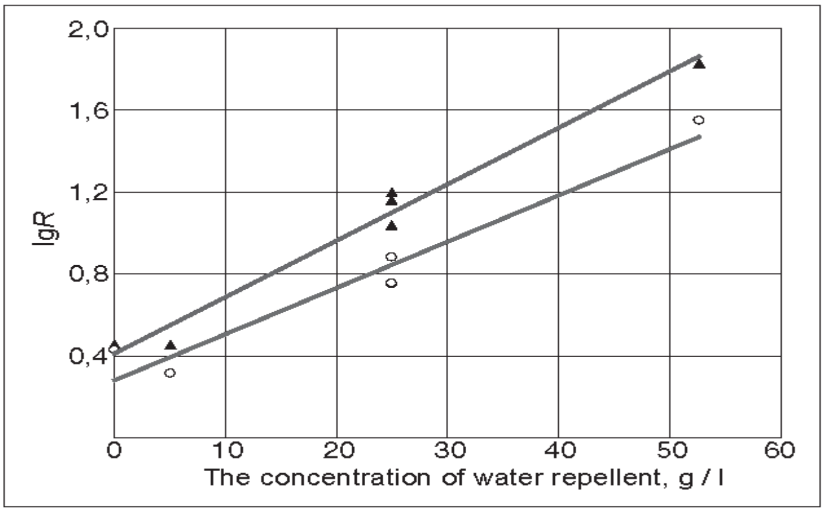

Figure 2: The dependence of resistance factors on the concentration of water repellent: ▲ IgR_{max}; o IgR_{res}

Table 2. The effect of the composition on the degree of restoration of the gas permeability of porous medium (injection volume of the composition is 1 p.v.)

Experiment	The concentration of water repellent, g/1l solvent	Resistance factor (When Injection a composition)		Gas Permeability µm²		Water Saturation %		The degree of permeability recovery, %
		Maximum	After injection 1p.v. composition	Absolute	With residual water	Before the exposure	After exposure	
Water repellent composition, a solution of ABR in PE								
9	0	0,94	0,94	0,792	0,677	29,6	26	111
12	25	1,72	1,67	0,299	0,216	36,6	26	131
16	25	1,93	1,61	0,516	0,416	27,7	26	99,3
10	25	1,02	1,02	1,540	1,470	11,6	1	103
20	50	1,46	1,46	0,967	0,916	14,5	9	121
Water repellent composition, ABR solution in a mixture of fuel oil M100(20% vol) and PE(80%)								
35	50	2,67	2,60	0,269	0,172	38,4	21	121
36	25	3.00	2,94	0,343	0,231	38,7	22	139
41	25	2,72	2,48	1,490	1,40	23,2	13	100

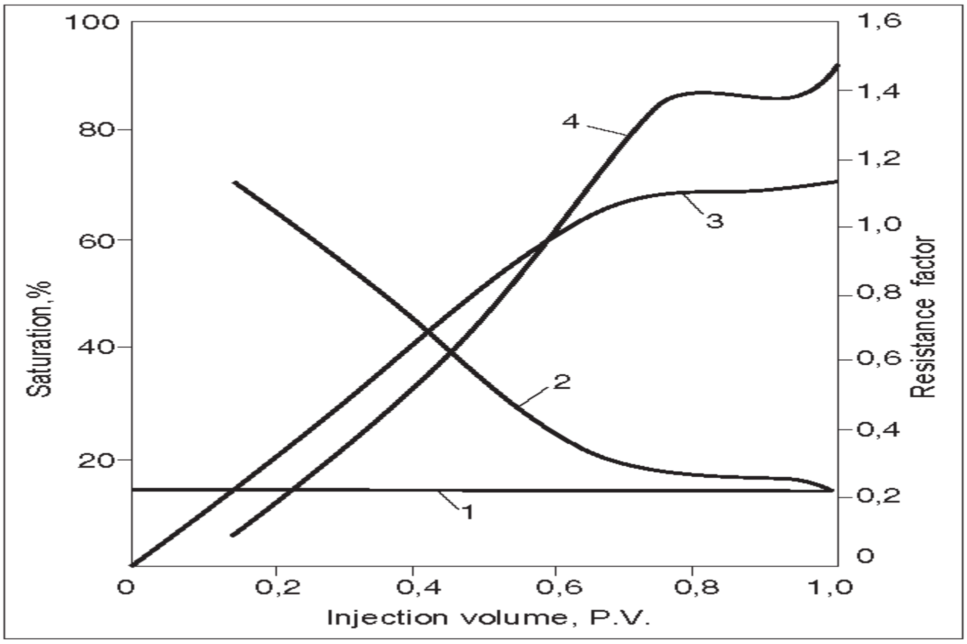

Figure 3: Dynamics of injection of a 50 g / l solution of water repellent into a gas-saturated porous medium (experiment 20): 1, 2, 3 — respectively, the saturation with gas, water and ABR in petroleum ether; 4 - R

Disassembly of the models showed that as a result of the blowing, PE evaporates completely. Injection of the composition into a porous medium and subsequent air blowing is accompanied by a decrease in the water saturation of porous medium, which explains the increase in the gas permeability of porous medium .The results of experiments 10 and 12 show that, the higher the initial water saturation the greater the increase in the gas permeability of the porous medium as a result of injection of a water-repellent composition. Changing the wettability of the rock under the action of a water repellent suppresses the capillary forces that hold water in the capillaries and on the surface of the sand, which facilitates the evaporation of water.

The study showed that the water repellent solution is able to significantly reduce the water permeability of water-saturated porous medium and increase the gas permeability of gas-saturated porous medium, i.e. it has the ability to selective water insulation. However, it is necessary to check the "selectivity" when injecting the composition, i.e. the ability of the water repellent solution to flow into porous medium of various saturations.

To assess the "flowing" selectivity of the water-repellent solution and pure solvent, experiments were carried out using two-layer models of a formation of gas and water-saturated interlayers. The experiments on two-layer formation models showed the following; When the volume of injection is more than 0.3 pore volume (p.v.) the water-repellent solution is more likely to enter the water-saturated interlayer than to the gas-saturated interlayer. After injecting 0.91–0.99 p.v. of the composition, the current ratio Qw/Qg reaches 5.22–5.26, which indicates a high selectivity when injecting the composition.

Water-repellent composition with additive of water-repellent film former

The composition of the ABR water repellent and volatile hydrocarbon solvent does not completely solve the problems of water isolation in gas wells. The composition contains a rather high concentration of the expensive reagent of the ABR water repellent and does not contribute to the strengthening of the bottom hole formation zone, i.e., it does not allow to combat with such a consequence of pulling up the water cone like sand removal and crumbling of the bottom hole zone of the Cenomanian horizon.

The reason for the removal of sand is the action of the wedging pressure of the wetting liquid (water). Water repellent, making the rock hydrophobic prevents the occurrence of wedging pressure. However, the ABR water repellent is soluble in water and therefore can be washed off from the surface of sandstone. It is possible to enhance the hydrophobic effect by including a water-insoluble film-forming agent in the composition of the water repellent.

In the first series of experiments (experiments 35, 36 and 41), the effect of the composition based on the ABR water repellent, M100 fuel oil and PE on the gas permeability of gas-saturated porous medium (with residual water) was investigated. The injection of a composition based on the ABR water repellent, M100 fuel oil and PE occurs without a significant increase in pressure drops.

The resistance factors (for comparison with water flow on the first stage of the experiments) are 2.48-2.85, which is slightly higher than when injecting the composition of "ABR + PE". As in the case of water repellent composition (ABR + PE), the restoration of gas permeability after injection of the composition based on ABR and fuel oil occurs rather quickly and completely, despite the high content of fuel oil in the injected composition (20%) (See Table 2).

In the case of relatively low-permeability porous medium (experiments 35 and 36), the degree of permeability recovery noticeably exceeds 100% (121and139%), which is explained by the evaporation of a significant part of the buried (bound) water in the gas stream.

The composition based on the ABR water repellent, fuel oil and volatile organic solvent does not reduce the gas permeability of porous medium (despite the high content of the heavy component). In case of high water content in porous medium it increases gas permeability by removing up to 55-57% of buried water. In experiment 39, the water-repellent composition “ABR + fuel oil M100 + PE” was investigated.

The data of table.1 show that, as a result of the injection of the composition, the water permeability of the porous medium decreased significantly (the maximum and residual resistance factors were 42.5 and 24, respectively), which is significantly higher than in the case of injection of the “ABR + PE” composition at the same concentration of water repellent ABR (25 g / l).

Thus, the introduction of fuel oil into the composition significantly enhances the water-insulating characteristics of the composition.

The selectivity of the composition injection based on “ABR water repellent + fuel oil M100 + PE” was invistigated according to the above described method using a two-layer model of the formation from gas and water-saturated interlayers. It was found that after injecting 0.78–0.86 p.v. of the composition, the current ratio Qwater / Qgas(water gas ratio) reaches value of about 7, i.e., the main amount of the composition enters the water-saturated interlayer.

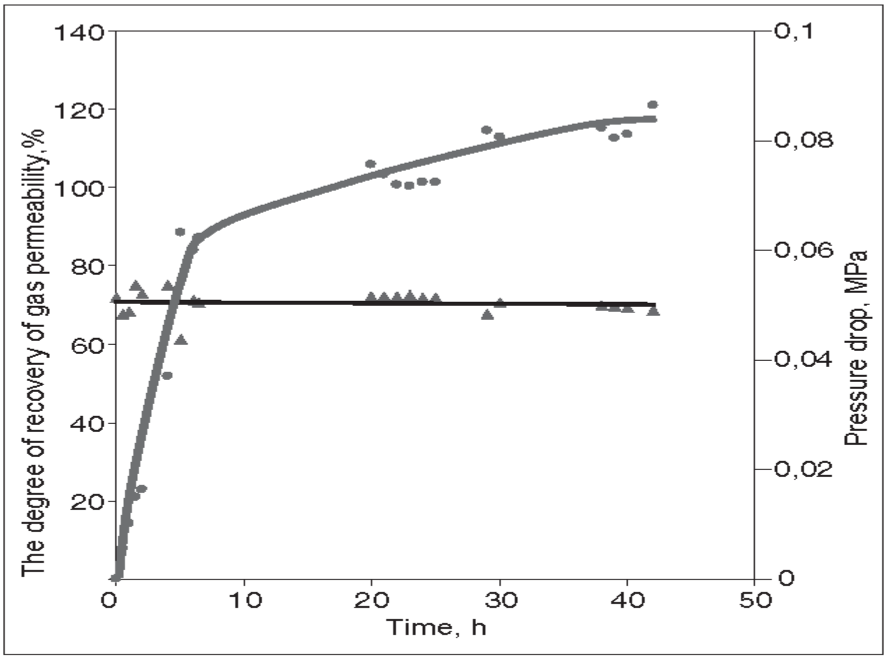

Figure 4: The dynamics of the restoration of gas permeability after injection of 50 g / l of the water repellent solution into a gas-saturated porous medium (experiment 20): ● degree of recovery; ▲ dP, MPa

Thus, the study showed that the addition of fuel oil to the water-repellent solution enhanced the water-insulating properties of the composition without impairing the other characteristics (no effect on gas permeability of gas-saturated porous medium and the selectivity during injection). As a water-repellent film former, we used fuel oil, which is a concentrate of surfactants.

The choice of heating oil for these purposes is due to its availability and low cost. However, viscous asphalt-resinous oil, oxidized oil, bitumen solutions, etc. should have similar film-forming properties.

The use of gas condensate and products of its processing as solvents

As a volatile hydrocarbon solvent, it is promising to use gas condensate and its primary processing products (stable gas condensate SC and light distillate of gas condensate DGCL). Initially, we conducted a study of the effect of compositions based on the ABR water repellent, M100 fuel oil and solvents SC, DGCL and mixed in equal volumes of DGCL + SC on gas permeability of gas-saturated porous medium.

Data Fig. 5 shows that the minimum recovery time of gas permeability is observed in the case of compositions based on PE and DGCL. In the case of using a composition based on SC as a solvent, the recovery time of permeability is noticeably longer, due to the lower volatility of this solvent.

The results obtained show that both tested solvents are suitable for solution preparation, but in the case of DGCL, the recovery time of 100% gas permeability is four times less. In DGCL, the content of fractions with a boiling point less than 30 ° C is about 60%, i.e., the use of this solvent is possible only in winter.

Moreover, the high content of light hydrocarbons in the solvent will contribute to the deposition of asphalt-resinous components of fuel oil (especially at low temperatures), i.e. the water-repellent composition may lose sedimentation stability. Therefore, it is necessary to use a mixture of SC and DGCL.

Despite the slower recovery rate of gas permeability (compared with the compositions of DGCL or PE), this mixed solvent is more technologically advanced and safe.

The presence of kerosene fraction in the hydrocarbons of SC improves the solubility of fuel oil in a hydrocarbon solvent, especially at low temperatures. It is clear that, if necessary, it is possible to increase the proportion of DGCL in the mixture and thereby reduce the recovery time of gas permeability.

In the next series of experiments, we studied the effect of solvent composition on the water-isolating properties of a composition based on the ABR water repellent and M100 fuel oil. The obtained experimental data show that the type of solvent generally has a small effect on the water-isolating characteristics of the composition.

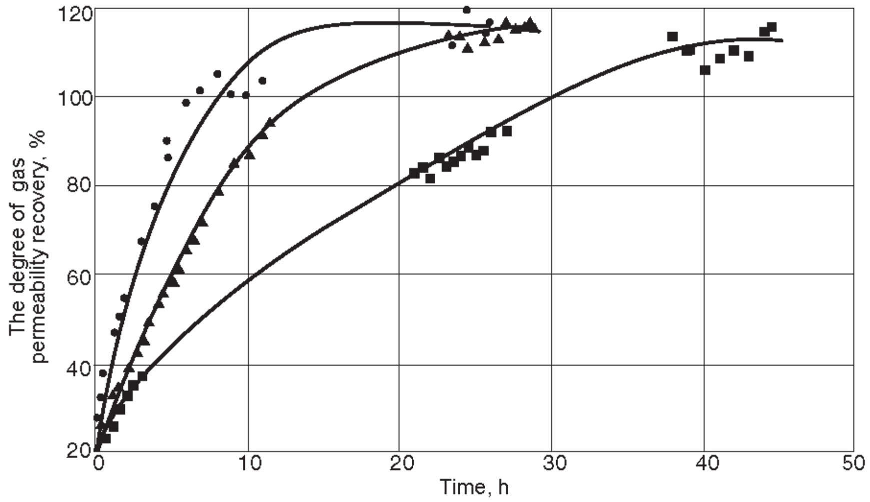

Figure 5: The effect of the organic solvent on the dynamics of restoration of gas permeability of porous medium (composition: 25 g /l ABR water repellent in a mixture of 10% fuel oil M100 + 90% solvent): ● DGCL; ▲ DGCL + SC; ■ Stable Condensate(SC)

Water-insulating degree of the composition with 10% vol. fuel oil is 87.5-90.9%, and at a content of 20% vol. fuel oil the degree of water insulation is 94.6-95.8%.Thus, the composition of the hydrocarbon solvent has little effect on the degree of water insulation. The greatest effect on the water-insulating properties of the compositions has the content of fuel oil. The increase in the concentration of fuel oil in the composition from 10 to 20% is accompanied by an increase in the degree of water insulation by 5-7%, and residual resistance factors increase by 2 times (from 8-12,1 to 18.5-24).

III. CONCLUSIONS

1- In general, the studies showed that the solution of water repellents in a volatile hydrocarbon solvent;
a) Does not adversely affect the gas permeability of gas-saturated porous medium (the solvent is easily removed from the porous medium by a gas stream);
b) Helps to remove residual water from gas-saturated porous medium and increase their gas permeability;
c) It has a high water insulating efficiency;
d) Exhibits selectivity during injection and enters mainly in water-saturated rather than gas-saturated porous medium.
2- As for gas condensate and products of its processing as solvents, the current research has shown that the increasing of fuel oil concentration in the solution will contribute significantly in hydro insulation of gas wells. For example increasing in the concentration of fuel oil in the composition from 10 to 20% contributes to an increase in the degree of water isolation by 5-7% and residual resistance factors by 2 times.
3- Thus, the solution of water repellents in a volatile hydrocarbon solvent is a promising composition for water insulation works in gas wells.
4- The proposed method is universal, technically easy to implement and does not require expensive costs.

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