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A NEW "EMIR" COMPOSITE FOR THE DECOLMATAGE OF OIL AND GAS LAYERS AFTER DRILLING AND DURING DEPOSIT EXPLOITATION TO INCREASE THE EFFICIENCY OF HYDROCARBON PRODUCTION

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Abstract: A new effective composite "Emir" has been created, which reduces the swelling of clay minerals and cleans the near-well zone of oil and gas-saturated layers from residues of drilling fluid, technical and formational water, resin-asphaltene components and paraffin; thereby restoring the efficiency of the well. The composite has high cleaning characteristics and the ability to foam in the presence of highly mineralized waters (up to 250 g/l), oil products and mineral acids. It also forms both straight and reverse mobile water-oil emulsions, which is important for cleaning oil layers. Based on the results of testing the "Emir" composite in production conditions on gas and oil wells, it was concluded that the use of "Emir" allows the discharge of hydrocarbon fluids to increase from 20% to 50% or more. The "Emir" composite can also be used on "low-flow" wells which have been clogged or eliminated for geological and technical reasons; this makes it possible to significantly increase the recoverable reserves of hydrocarbons in various oil and gas-bearing regions, especially taking into account the small volumes of drilling and the low success rate of searching for new oil and gas fields.

Keywords: oil, gas, composite, decolmatage, reservoir, discharge, well

1. Introduction

Industrial observations have shown that the flushing fluid and its filtrate significantly affect the development of wells and bed fluid discharge. Penetrating into the layer, they change the structure of the pore space and the permeability of the near-well zone of the layer: they form a zone of colmatage there, in the pores of which the dispersed phase of flushing fluid penetrates. The depth of penetration depends mainly on (1) the ratio of the flushing fluid granulometric composition and the pore space structure; (2) pressure drops during drilling; (3) duration of the flushing fluid impact on the reservoir rock [1].

Deterioration of the filtration-capacity parameters of the near-well zone of the bed due to the penetration of filtrate into the pore space of the bottomhole zone is associated with the following factors: (1) swelling of clay minerals under the action of the filtrate; (2) the formation of emulsions of the filtrate with a bed fluid; (3) penetration into the pore space (together with the filtrate) of high molecular weight polymers and/or solid phase particles (bentonite, hematite, cement, drilled rock) [2].

Laboratory studies have shown [2, 3] that the intrusion of the flushing fluid clay phase into the layer occurs even at low permeability ($1–10 \cdot 10^{-3}$ μm^2). With the increasing permeability of productive horizons, the degree of negative impact of the solid phase on the reservoir increases while the liquid phase decreases. It is believed that clay particles begin to penetrate into the pore space at a permeability of 0.25–0.28 μm^2 [2].

It should be noted that in low-permeable layers (which are characteristic of deposits in Ukraine, especially in Pre-Carpathian region), the decrease in permeability should be more associated with the influence of the flushing fluids filtrates. The depth of the penetration zone of these filtrates can vary from a few millimetres [4] to several meters [5]. It is noted that a greater depth of filtrate penetration is recorded in less permeable reservoirs [6].

When analyzing the impact of filtrates on reservoir layers, it is necessary to consider the features of technological additives and their impact on reservoir layers, especially on the swelling of the existing clay varieties. Generally, geological prospecting organizations use reagents of general-improving actions for the preparation of flushing fluids, mainly soda ash, carbon-alkaline or peat-alkaline reagents, etc. Soda ash promotes the process of the peptization of the colloidal fraction, which is expressed in improving the rheological properties of the flushing fluid and reducing filtration rates. Carbon-alkaline and peat-alkaline reagents stabilize the clay solution and cause a decrease in the filtration rate. Soda ash is almost always injected simultaneously with the clay to reduce the solids content or eliminate its presence, and carbon-alkaline and peat-alkaline reagents – after stirring the solution.

However, there is one important feature: "humane" reagents are only used when there is no swelling clay in the geological section. Therefore, only suspensions that are treated with lignosulphonate should be used for the destruction of clays and anhydrites [7].

The study of the influence of chemical reagent solutions on the phase permeability of the core from the Palaeogene sediments of the Inner Zone of the Precarpathian Foredeep show that chemical reagents such as gipan, Na_2CO_3, carbon-alkaline reagent, condensed sulphite-alcohol bard have the highest colmatage ability, and carboxymethyl cellulose, carbophen, chlorides and chromates of Na and K the lowest [1, 5].

Chemical reagents of the first group and those belonging to the class of peptizers, cause the processes of the disintegration of sticky colloidal aggregates of clay, its lumps or clots into smaller fragments and primary particles. Thus, the technological and rheological parameters of flushing fluids are improved [8].

Peptization, on the one hand, is necessary for the preparation of high-quality flushing fluids but it also causes the processes of disintegration and destruction of the sand-clay rocks structure, leading to swelling and clogging of the pore space of the reservoir.

Studies show that peptization occurs when the charge of particles increases and causes hydrophilization of their surface, so it is undesirable in the interaction of drilling mud with clay rocks, from which the walls of the wellbore can be composed [8].

This shows that the opening of gas- and oil-bearing layers without drilling technology and without proper chemical treatment of clay solutions leads to cases where promising objects are "dry" or the hydrocarbon fluid discharge does not meet the criteria for commissioning wells. In both cases, this is caused by clogging of the bed with flushing fluid or its filtrate. Moreover, the filtrate penetrates much more deeply into the bed, leading to the swelling of clay rocks [2].

2. Purpose of the work

It is known that there are various problems in the process of the drilling and operation of deep wells for oil and gas. We propose a solution to one of them by creating a new complex reagent for cleaning the near-well zone. This reagent has specific properties that restore wells and increase hydrocarbon discharge.

During the research, a number of complex reagents were created [9–13]. The most universal for use in the oil and gas complex is the composite "Emir" [12], which has the following characteristics:

- the component composition reduces the swelling of clay minerals due to the processes of inhibition and reverse osmosis;
- the selected surfactants effectively emulsify the oil (condensate) with stratal water and/or technical water with the formation of a homogeneous emulsion which can subsequently be easily removed from the bed;
- a high ability to foam in both conditions of highly mineralized waters (to 200 g/l), and in the presence of liquid oil products (including condensate) and mineral acids;
- the existing set of properties, which allows an effective mechanism to be used for cleaning the bottomhole zone of clogging products to restore the well.

3. Results

3.1. Comparison of the efficiency of primary "Composite" and the current processing methods

We studied the efficiency of primary "Composite" (hereinafter Composite) in comparison with the current treatment methods on models of beds clogged with swelling of clay minerals: model N1 – we studied the changes in the permeability of the clogged reservoir before and after treatment with acid; model N2 – we investigated the permeability of the clogged reservoir before and after treatment with Composite.

In both cases, the layers were represented by siltstone and sand-clay varieties with the following filtration-capacity parameters: (1) absolute gas permeability (dry sample), k = 6.9 mD; (2) residual, or irreducible, water saturation, S_{wi} = 40.0%; (3) effective gas permeability in the presence of residual water, k_g = 0.2 mD; (4) porosity in the case of water saturation with mineralization of 15 g/l, n = 21.9%.

The hydrochloric acid treatment of the model included the following operations:

1) We simulated the residual water saturation of the reservoir with stratal water and studied the structure of the pore space; the result – the effective permeability of the model decreased from 6.9 mD to 0.4 mD.
2) The model was re-saturated with technical water for swelling of clay minerals; the result – the effective gas permeability after re-saturation with technical water decreased from 0.4 mD to 0.2 mD.
3) The rock, clogged with swelling of clay minerals, was treated with hydrochloric acid; the result – the effective gas permeability increased from 0.2 mD to 0.7 mD, i.e. 3.5 times.
4) Clogged model N1 after hydrochloric acid treatment was further treated with Composite; the result is that the effective gas permeability increased from 0.7 mD to 2.6 mD, i.e. increased 3.7 times compared to that which was after hydrochloric acid treatment (Figs. 1 and 2).

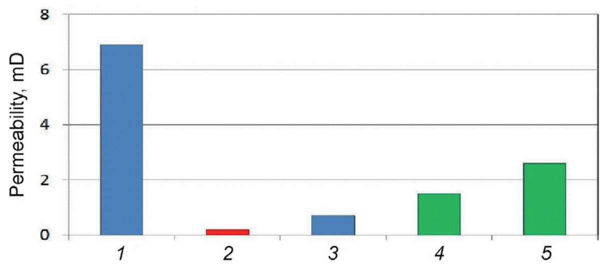

Fig. 1. Change in the effective gas permeability of the clogged bed model before and after its treatment with acid and Composite: 1 – dry sample; 2 – clogged sample; 3 – after HCl treatment; 4, 5 – after Composite treatment: 4 – on the first day, 5 – on the third day

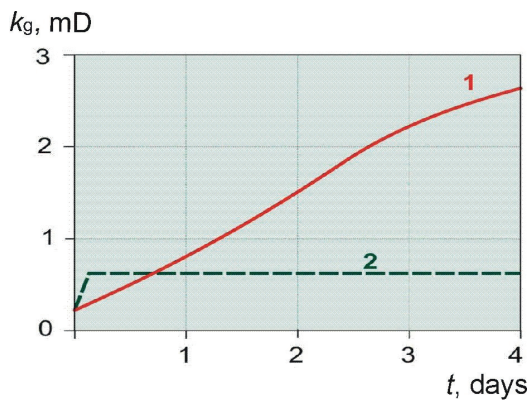

Fig. 2. Change in effective gas permeability when acting on the clogged model of the Composite (line 1) and 10% hydrochloric acid solution (line 2)

The following results were obtained for model N2: during step (1) (see above) the effective permeability of the model decreased from 6.9 mD to 0.4 mD; in step (2), the effective gas permeability after additional saturation with technical water decreased from 0.4 mD to 0.2 mD;

in the third stage, the rock clogged with swelling of clay minerals was treated with Composite, the result of which – the effective gas permeability increased from 0.2 mD to 2.6 mD, i.e., it increased 13 times (see Figs. 1 and 2).

Therefore, the only Composite treatment of the model, clogged by the swelling of clay rocks, is more effective compared to hydrochloric acid treatment.

Positive results of laboratory modelling were confirmed in practice: in the bottomhole zone of the H-1 well the oil-saturated bed was cleaned of clogging, causing a significant drop in oil discharge. In the process of work, acid treatment, washing of the clogged bed with kerosene and treatment with Composite were performed (Fig. 3).

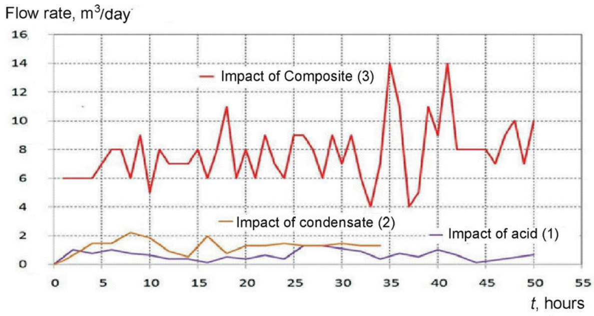

Fig. 3. Comparison of the flow rate of oil well H-1 after alternating exposure to the clogged bed of acid (1), condensate (2) and Composite (3)

To find out the possible reasons for the change in the permeability of the model after the application of different reagents, we compared thin sections of the reservoir bed after exposure to hydrochloric acid and Composite (Fig. 4).

The clear texture of the thin section indicates that the increase in the effective permeability of the model in the case of Composite impact on the rock is due to the reduction of the swelling of the clay varieties.

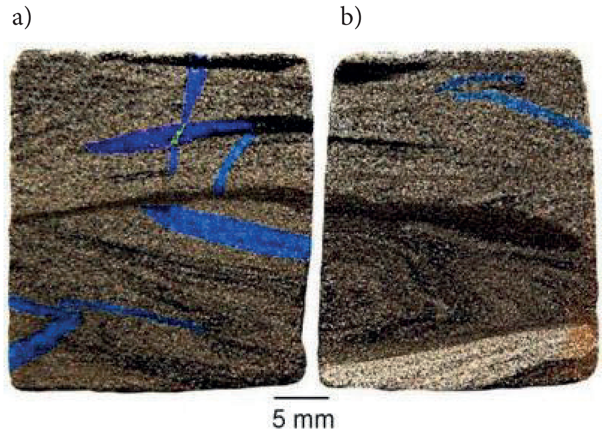

Fig. 4. Comparison of the thin sections of reservoir bed after exposure to the rock of hydrochloric acid (a) and Composite (b) treatment (the research was carried out by Yu. Fedoryshyn)

3.2. Solving the problem of bed flooding and the formation of complex emulsions

As for the problem of bed flooding, the composition of the Composite was selected so as to emulsify the oil with mineralized stratal water, and then the formed homogeneous emulsion is effectively removed from the bed (Fig. 5).

Purification of the bed from emulsions formed by Composite is as follows: during the interaction of Composite with oil, a highly mobile emulsion is formed, the viscosity of which is less than the viscosity of each source component; this allows quality and effortless removal of clogging and thereby increases the hydrocarbons discharge (Fig. 6).

Note that the oil discharge after the application of Composite on the well H-1 is kept at a constant level for a long time (Fig. 7).

Fig. 5. Experiments to find out the optimal composition of the Composite in order to obtain a homogeneous water-oil emulsion (see samples 1, 2)

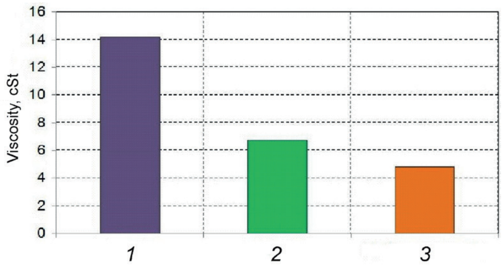

Fig. 6. Comparison of the viscosity of oil from the Starosambirske deposit (1), Composite (2) and the newly formed oil + Composite emulsion (3) (1:1)

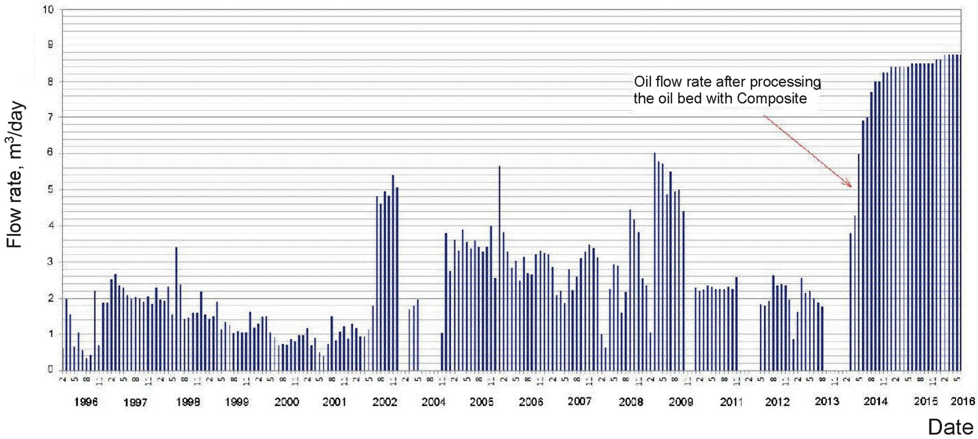

Fig. 7. Oil discharge in well H-1 before and after treatment of the clogged bed with Composite

This is due to the fact that due to the action of Composite on the bed, the surface of the mineral grains of the reservoir is probably hydrophobized. This, in turn, eliminates the threat of formation of resin-asphaltene layers, which reduce (complicate) the permeability of the bottomhole zone.

3.3. Improving the original Composite and studying the effectiveness of the composite "Emir"

To improve the original Composite [11–13], a new composite was created under the trademark "Emir" [12], which significantly accelerates the dynamics of restoring the effective gas permeability of reservoir rocks clogged by the swelling of clay rocks. It transpired that five hours after treatment with the composite "Emir", the permeability of the bed is restored by 65–70%, while the original Composite only gives a similar result on the third day (Fig. 8).

Studies of the composite "Emir" effectiveness were performed on a model of sand-clay bed-reservoir from Precarpathian region, which had the following filtration-capacity parameters: (1) absolute gas permeability (dry sample), k = 29.6 mD; (2) residual, or irreducible, water saturation, S_{wi} = 50.0%; (3) effective gas permeability in the presence of residual water, k_g = 8.2 mD; (4) porosity in the case of water saturation with mineralization of 15 g/l, n = 20.9%.

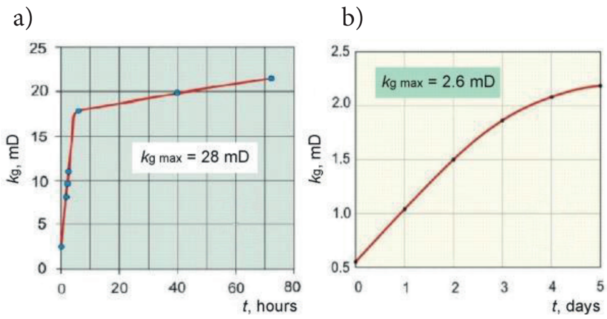

Fig. 8. Dynamics of the recovery of the effective permeability of reservoirs clogged by swelling clays after processing their models with the "Emir" composite (a) and the original Composite (b)

The parameters of the bed pore space structure are shown in Figure 9: the proportion of sub-capillary pores that are filled with residual water and have a radius <0.3 μm, is 45%; the proportion of capillary pores with a radius of 0.3–3.0 μm – 35%; the remaining volume (20%) consists of supra-capillary pores with a radius of 3–100 μm.

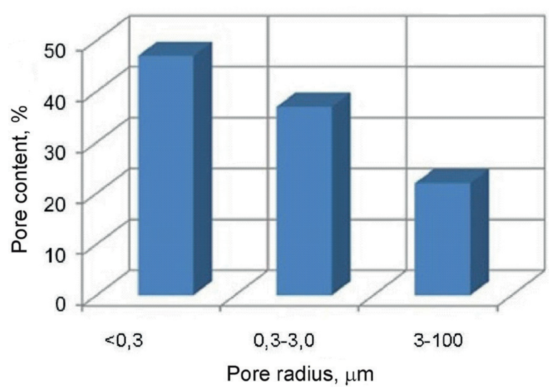

Fig. 9. Porometric characteristics of the model for studying the effectiveness of the "Emir" composite: <0.3 µm – sub-capillary pores; 0.3–3.0 µm – capillary; 3–100 µm – supra-capillary

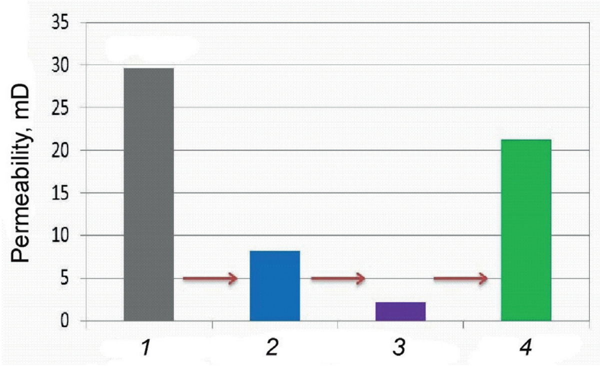

Fig. 10. Change in the absolute permeability of the model (anhydrous sample) (1) during the simulation of residual water saturation (2), clogging with technical water (3) and the effect on the model of the "Emir" composite (4)

The efficiency of the "Emir" composite was investigated on the bed model using the following operations (Fig. 10):

1) We simulated the residual water saturation of the reservoir with stratal water and studied the structure of the pore space; the result was that the effective permeability of the model decreased from 19.6 mD to 8.2 mD.
2) The model was resaturated with technical water for swelling of clay minerals; the result – the effective gas permeability after re-saturation with technical water decreased from 8.2 mD to 2.2 mD.
3) The rock, clogged with swelling of clay minerals, was treated with Composite; the result – the effective gas permeability increased from 2.2 mD to 17.0 mD in seven hours and to 72.7 mD in 72 hours, i.e. it increased 11.6 times.

The absolute gas permeability of the model is 29.6 mD. The results show that the restoration of the permeability of the clogged model with the "Emir" composite is about 72% of the absolute (see Fig. 8).

The phase permeability of the layer model at residual water saturation K_{ws} = 50% is 8.2 mD. The results of modelling the purification of the clogged model show that "Emir", acting on the rock, not only removes technical water from the clogged model, but also adsorption-bound water of the pore space, which is in sub-capillaries at a permeability of 8.2 mD.

Also, "Emir" showed better results compared to the original Composite during the dissolution of resin-asphaltene components (their sample was taken from the pump-compressor pipes of the oil well) (Fig. 11).

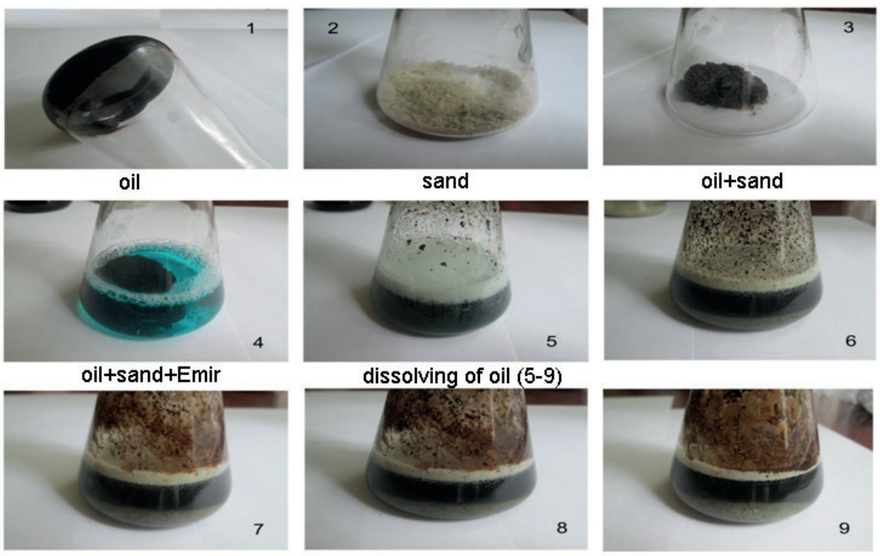

Fig. 11. Dissolving heavy, high-resin and paraffinic oil with the help of the "Emir" composite

4. Practical significance

4.1. Scheme for cleaning clogged layers

Taking into account the positive results of laboratory studies of the "Emir" composite (especially the rapid recovery of the permeability of the clogged sand-clay bed), it was used to restore the operation of gas wells, the bottomhole zone of which is clogged with stratal water and swelling of clay rocks.

In real conditions, it is proposed to use the composite "Emir" on gas wells as a "bath" with its partial pushing into the bed to eliminate the swelling of the clays and to flood the productive reservoir in order to restore the well (Fig. 12).

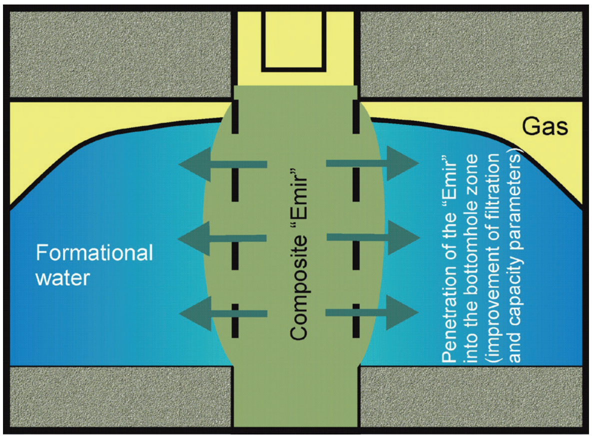

Fig. 12. Application of the "Emir" composite in the form of a "bath" with partial pressing into the bed to improve the filtration and capacity parameters of the near-well zone

The process of modelling the bed decolmatage showed that the bed under the action of the composite significantly improves its filtration and capacity parameters. In our opinion, similar results can be expected in the near-well zone of the clogged bed-reservoir after treatment by "Emir": the improvement of filtration-capacitive parameters in the near zone will lead to an increase in the filtration rate of fluid from the near-well zone to the wellbore (Fig. 13a). Since the rate of filtration of water from the near zone to the wellbore will be much higher than this speed from the depth of the bed, the formational pressure in the near-well zone will decrease due to the slow supply of water from the far zone of the bed.

A decrease in water pressure in the near-well zone will lead to the fact that the gas, which has a higher formational pressure, will squeeze water from the flooded part of the formation; and thus the position of the gas-water contact zone will be restored, improving well operations (see Fig. 13b).

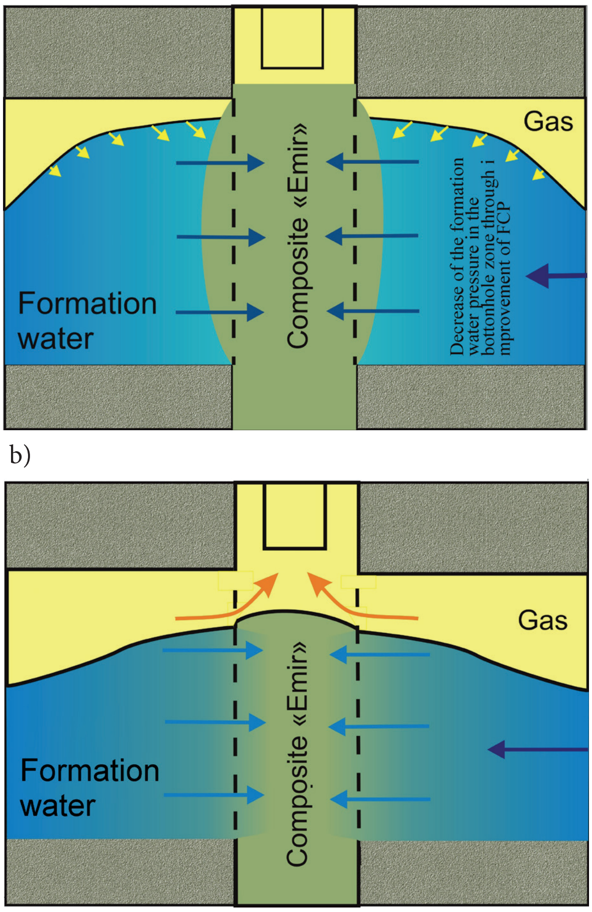

Fig. 13. Change in the character of fluid saturation of the near-well zone under the action of the "Emir" composite

As for the collector layer clogged by the swelling of clay varieties, the "Emir" composite contains inhibitors that eliminate the peptization of clays, as well as components that cause the phenomenon of reverse osmosis, due to which the amount of bound (adsorbed) water in the rock decreases. The removal of excess adsorbed water from the rock is confirmed by the results of laboratory modelling of bed decolmatage using the "Emir" composite: the rock treated with this composite has greater permeability than the one in which the presence of residual water was previously simulated (see Fig. 11).

4.2. Application of "Emir" composite on wells

In the course of research and production testing, the "Emir" composite was used to improve the operation of gas wells in the Hutsulivske, Debeslavetske, Pylypivske, Sheremetivske and other fields. The bottom zone of these wells was clogged with the remains of flushing fluids, technical waters or swelling of clay rocks.

We shall present the scheme of using the "Emir" composite at the well. For the effective cleaning of bed, it is necessary that the "Emir" penetrates into the near-well zone of the clogged reservoir. For this, it is pumped into the well through the annular space with a compressor. After pressing the composite to the hole, we start pumping nitrogen to a pressure value that will exceed the formational pressure but lower than the column pressing pressure. Then the well is closed, and the "Emir" composite is kept in the layer for 48 hours with pressure control at the wellhead.

If the pressure after a day is equal to the formational pressure, the well is drained, the "Emir" composite is removed, and the well is put back into operation. If the pressure in the well has not changed, then it is necessary to pump the well with nitrogen to the pressure at which it begins to absorb nitrogen, and leave it for a day. Then the well is drained, the composite is removed, and the well is put into operation.

The scheme of the application of the composite on the well is shown in Figure 14.

It is important to note that the results of the application of the composite in real conditions indicate, that in the process of cleaning the beds-reservoirs from colmatents with the "Emir" composite, these colmatents are carried out in the form of a gas-foam system to the day surface without significant effort, which leads to an improvement in well operation and an increase in the gas discharge from 20% to 50% or more (Fig. 15).

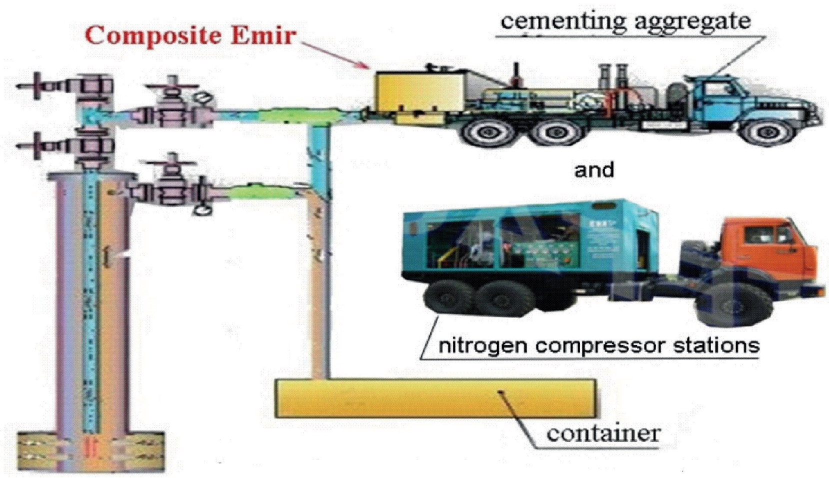

Fig. 14. The scheme of the application of the composite on the well

Fig. 15. Removal of colmatents from the well in the form of a gas-foam mixture to the day surface

5. Conclusions

Today, in many cases the efficiency of oil and gas wells cannot be considered satisfactory, especially in sand-clay section conditions, therefore the problem of developing new highly effective reagents and methods to improve the intensification of the oil and gas production process is both urgent and important.

Our main task was to create such a new reagent for cleaning the near-well zone, the specific properties of which would ensure the recovery of the wells and increase the discharge of hydrocarbons.

The main role in the creation of the "Emir" composite was assigned to the selection of suitable surfactants with high emulsifying characteristics. After all, when working with oil-saturated beds, the emulsification process of the system is of great importance: firstly, it improves the penetration of the composite into the pore space and the access of its components to the swollen clay varieties, and secondly, makes it possible to form a homogeneous mobile emulsion from the complex multiphase system of clogged bed "gas–oil–water", and this emulsion is subsequently removed from the bed.

The testing of the "Emir" composite in production conditions confirmed the following:

– the "Emir" composite eliminates the clogging of the bottomhole zone of the gas-saturated bed with technical (formational) waters and filtrate of flushing fluids, thereby increasing the gas discharge from 20% to 50% or more;
– the composite reduces the swelling of clay minerals, thanks to which the operation of beds clogged with drilling fluid residues is restored; this makes it possible to also use "Emir" as a perforation liquid;
– unlike existing analogues, the "Emir" composite has high foaming attributes in conditions of highly mineralized waters (up to 250 g/l) and in the presence of liquid hydrocarbons (including condensate), which makes it possible to use "Emir" to remove formational water from the wellbore.

Therefore, the use of the "Emir" composite will make it possible to restore the operations of clogged wells and increase the discharge of working wells, especially if there are sandy-clay rocks in the section. Currently, insignificant volumes of drilling and a low success rate of searching for new oil and gas fields in the country have been recorded. Therefore, the introduction of the "Emir" composite and the above-described technology on low-flow or production wells, previously liquidated for geological and technical reasons, will make it possible to significantly increase the extraction reserves of hydrocarbons in Ukraine.

Author Contributions: All of the authors contributed to the acquisition of data and the writing of this manuscript:

– development and creation of an industrial sample of the "Emir" composite – Ihor Hubych;
– review and editing – Yurii Krupskyi, Mykola Pavlyn;
– industrial tests – Vasyl Viitenko, Vitalii Feichuk.

Conflicts of Interest: The authors declare no conflict of interest.

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