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RESULTS OF COMPLEX TECHNOLOGY SIMULATION FOR LOW-PERMEABLE RESERVOIR DEVELOPMENT

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ABSTRACT

The article presents the calculation results for the implementation of the integrated method of increasing oil recovery factor, including the multistage hydraulic fracturing in horizontal wells, followed by displacement of residual oil with water or gases of different composition. To evaluate the effectiveness of these technologies injection of various displacement agents has been simulated using a new approach based on the combination of local of dual and compositional medium models. The obtained results indicate the ineffectiveness of the natural modes and water injection for the conditions under consideration, as well as a significant impact of gas agent type, and moreover, location of the horizontal well to a large extent.

Keywords: efficiency, low-permeable, deposit development, multi-stage hydraulic fracturing, simulation, gaseous displacement agent injection.

1. INTRODUCTION

The practice of development of hard-to-recover oil reserves from low-permeable reservoirs is greatly associated with use of the hydraulic fracturing (HF). Development of the multi-stage HF technology and its application in horizontal wells without maintenance of formation pressure does not allow for substantial increase of oil reserve development efficiency. Using water to maintain formation pressure and also as a displacement agent for development of formations with low filtration properties is not effective. Sufficient experience in implementation of gas methods for oil yield enhancement has been accumulated in the global practice of development of fields with low-permeable reservoirs. Development of new enhanced oil recovery technologies is aimed at combination of various stimulation techniques. A combination of injection of gas agents with multi-stage hydraulic frequency in horizontal wells can serve as an example of such new technology development.

The subject of research is low-permeable low-viscosity oil deposits, reserves of which pertain to the hard-to-recover category.

2. THEORETICAL JUSTIFICATION AND RELATED WORK

Currently a lot of HF simulation techniques on hydrodynamics models are known. The negative skin-factor or modification of multiplier productivity index (Well MPI) using modified coefficients of the "well-cell" link, as well as and fracture simulation in an explicit form by means of the grid refinement have become the most common ones [1, 3]. Hydraulic fractures can be simulated by creation of additional links [2].

Development of a shale gas field with horizontal wells with multi-stage HF was simulated in [1]. The simulation was carried out on a sector. Various approaches to hydraulic fracture simulation were used: fractures were simulated in an explicit form by using logarithmic refinement of the grid (tartan-grid), fracture simulation was also used in an implicit form by using the double porosity/double permeability ($2\phi/2k$) and double porosity/single permeability ($2\phi/1k$) model. And in the first case ($2\phi/2k$), the recovery results proved to be 5% higher compared to the simulation by the logarithmic grid refinement, in the second case –13% lower, but still considerable advantage could be gained in the machine time. Finally, a conclusion was made that the multi-stage fracturing simulation technique using the double medium model was admissible and required further research and study.

This work suggests a fundamentally new approach to hydraulic fracture simulation for low-permeable heavily dissected multi-formation deposit based on the setting of multi-stage hydraulic fractures in an implicit form using the local double environment model (only in the area of setting hydraulic fractures) without changing the properties of the remaining formation volume. It proposes using a compositional model of the formation fluid together with the local double medium to research displacement efficiency when injecting various gas agents.

Geological and physical characteristics of the research subject: Assessment of process efficiency of the complex technology is carried out for conditions of a multiple formation site with water permeability less than 10 Dm/Pa*sec. A multiple formation facility comprises four formations; difference in depths of occurrence of the first and the fourth formation does not exceed 100 m, with

permeability below 0.005 mcm^2 saturated with low-viscosity oil less than 1 mPa·sec., and oil-unsaturated thickness less than 2 m. Specific features of the structure of these formations can include their considerable dissection and low net-to-gross sand coefficient. Horizontal wells are drilled in the third formation, and hydraulic fractures penetrate all formations (Figure-1). Selection of a formation to drill a horizontal well is connected with the height limitation of the formed fracture.
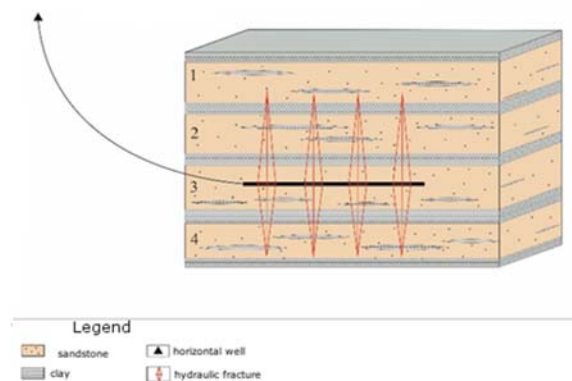

Figure-1. Schematic section of the HF.

3. CALCULATION METHOD

Computational experiments were carried out using Open Flow software (Beicip Franlab, France)that allowed simulating hydraulic fractures in an implicit form using a local double environment model (only in the area of hydraulic fracture setting) without changing the properties of the remaining formation volume. Corresponding properties of the initial enlarged model was set as porosity and permeability of the matrix. Dimensions of the matrix blocks were accepted equal to 25 m x 75 m x 70 m. Such dimensions were chosen on the basis of the obtained actual characteristics of fractures after multi-stage hydraulic structuring in wells: half-length of the fracture was 75 m, the fracture penetrates all formations at the fracture height of 70 m (Figure-2).

An option of development in the natural drive with performance of multi-sectional HF of the formation was accepted as a comparison base. According to the calculation results, the oil recovery factor on the elastic drive was 0.088.
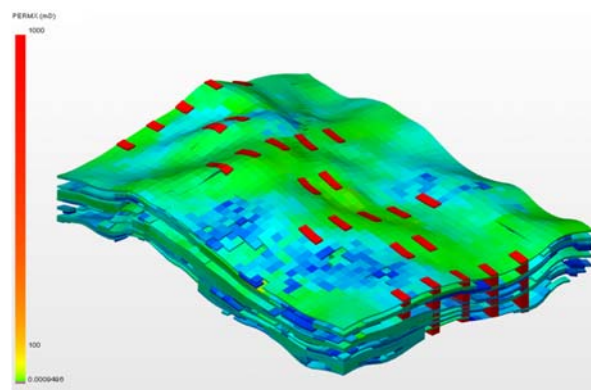

Figure-2. Simulation of multi-stage hydraulic fractures with a medium having double porosity and permeability.

The wells located between the production wells were reassigned for injection to assess efficiency of the water-flooding pattern. Performance of water injection wells to maintain formation pressure is of a"single-point" nature determined both by the position of the well itself, and its position relative to the of water injection wells. A considerable inconsistency of the formation even with quite dense grid of horizontal wells with completed multi-stage HF did not allow obtaining oil recovery factor (ORF) any higher than 0.114, even not considering the quality of the injected water. For the conditions of low-permeable reservoir, accounting of size and concentration of solid weighted particles in the injected water can appreciably decrease the formation volume undergoing the displacement process (Figure-3). In conditions of a low-permeable reservoir and at a formation pressure that is close to the saturation pressure, excess of the well capacity over some maximum value leads to sharper drop of the capacity and reduction of the general recovery of reserves. Such results are connected both with quicker gas breakthrough decreasing the coefficient of formation exposure to the stimulation, and low value of piezo-conductivity that does not allow for effective maintenance of the formation pressure during quicker recovery of the extractable reserves.
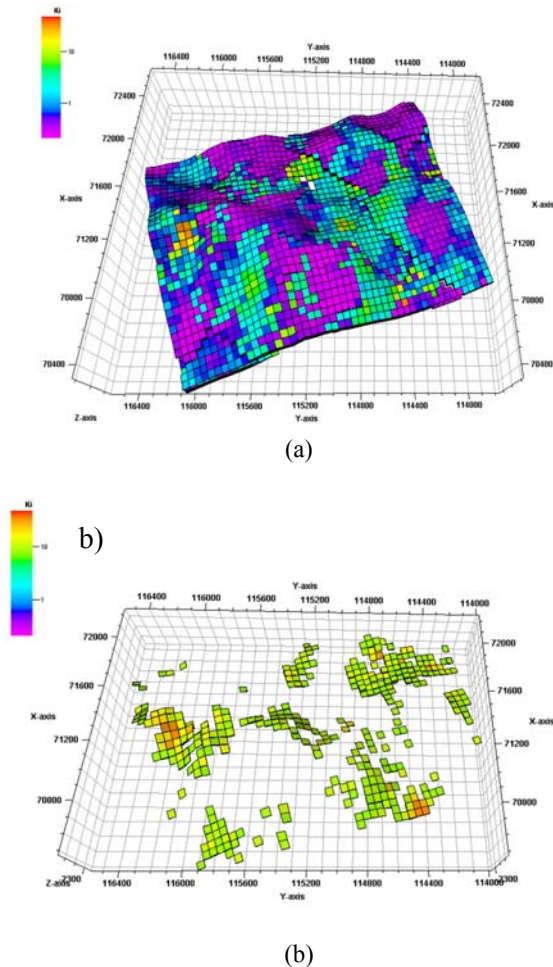
(a)

(b)

Figure-3. Distribution of permeability of active cells in
the model without regard to (a) and with regard to
(b) the quality of injected water.

Under such geological and physical conditions,
the conventional flooding is not an effective method for oil
reserve recovery. The obtained results became the basis
for performance of a complex of computational
experiments for search of an effective working oil
displacement agent. Various gases were considered as
displacement agents: methane, carbon dioxide, nitrogen,
flue gases, enriched gas, associated petroleum gas (APG).

4. SIMULATION RESULTS

The process of development in conditions of the
low-permeable reservoir was simulated using the local
double medium model in the complex with the
compositional hydrodynamic model.

The purpose of the research was to determine
influence of formation development nature and type of the
injected gas on efficiency of oil displacement in a multi-
formation object. Based on the results of the calculation,
all options were ranged by the ORF design value (Table-
1).

For the first three formations, including the one
with the horizontal well, at different numeric values of
ORF, the efficiency ratio of injecting the three gases:
associated petroleum gas, carbon dioxide and methane,
retains.

Due to pressure redistribution in vertical fractures
for all three gases, the maximum ORFs were acquired for
the second formation located above the formation with
horizontal wells.

The maximum oil recovery factor was obtained
during re-injection of the recovered gas.

Since miscibility pressure for each gas depends
on thermo baric conditions of formations and molecular
weight of oil, then, when injecting enriched gas, carbon
dioxide and re-injecting recovered gas near the water
injection well, the process of miscible displacement goes
on resulting in achievement of high values of displacement
coefficient. While formation pressure decreases and such
working agents as methane and nitrogen go further from
the injection area, only the immiscible character of
displacement will be implemented. ORF curves for
various gases in various formations are shown in Figure-4.
Comparison of the design value of the oil recovery factor
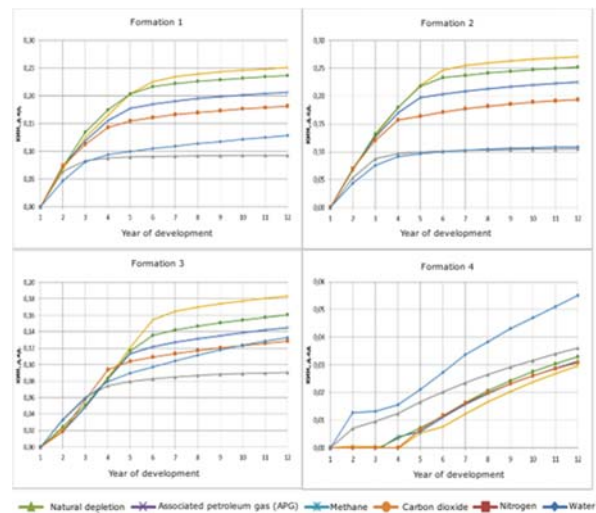is shown in Figure-5.

Figure-4. Oil recovery factor curves depending on the
injected gas in various formations.

Change of coverage coefficient due to the
injected agent is determined by the fact that the parameter
in question is a complex value considering the degree of
involvement of each formation, in terms of thickness and
area, depending not only on their filtration characteristics,
but also on the remoteness of the formations according to
the depth of occurrence from the water injection well, and,
consequently, on the effect of the gravitation force.

Nature of formation pressure change for one
formation (formation 2) when injecting various gases is
illustrated in Figure-4. Rise of pressure in the early period

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of gas injection, except for re-injection of the recovered gas, is connected with accepted conditions of computation, which do not limit their injection volumes.
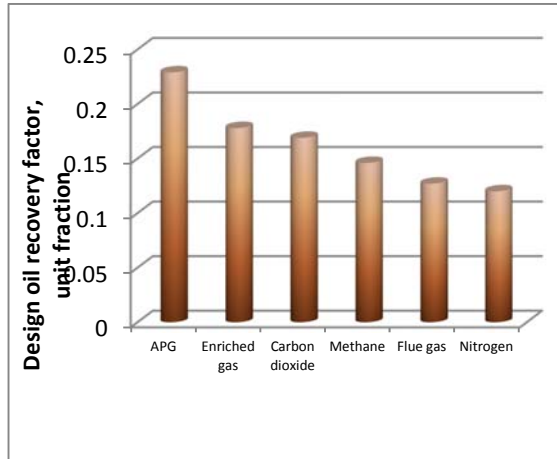

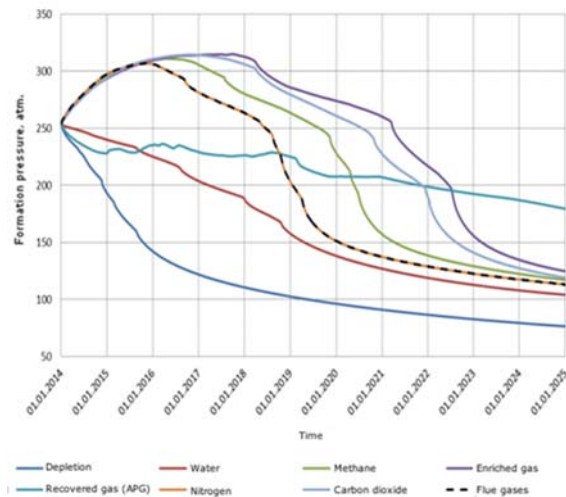**Figure-5.** Comparison of design values of oil recovery factor for gas displacement agents.

Figure-6. Dynamics of formation pressure during injection of various agents (Formation 2).

Influence of hydraulic fractures on the reservoir production: Both gravitation forces, and filtration-volume properties of formations and their orientation relative to the well with the horizontal shaft influence the formation pressure maintenance level. The assumption about the adverse effect of hydraulic fractures on the nature of oil displacement by any working agent was confirmed in the form of the formation pressure dynamics. In the considered options, the horizontal shaft of the wells runs through the third formation. The maximum volume of gas is introduced into the overlaying formation 2, and then the remaining volume of gas is

redistributed between the third formation and upper formation 1. Lower formation 4 is almost not involved in the displacement process during gas injection. Thus, the created system of fractures caused the inconsistent nature of distribution of the injected gas between the formations. The most effective method for the underlying formation is injection of water as the heaviest working agent.

For comparison, the formation pressure change curve is provided in Figures 7, 8 for all formations during re-injection of recovered gas and nitrogen, respectively. Dynamics of the formation pressure of the miscible displacement, which is implemented during re-injection of recovered gas in all formations, has a smooth curve, which proves more effective formation pressure maintenance system, and, as a consequence, results in a higher coefficient of formation coverage by the stimulation in comparison with the immiscible and much more inconsistent character of nitrogen distribution in the formations.
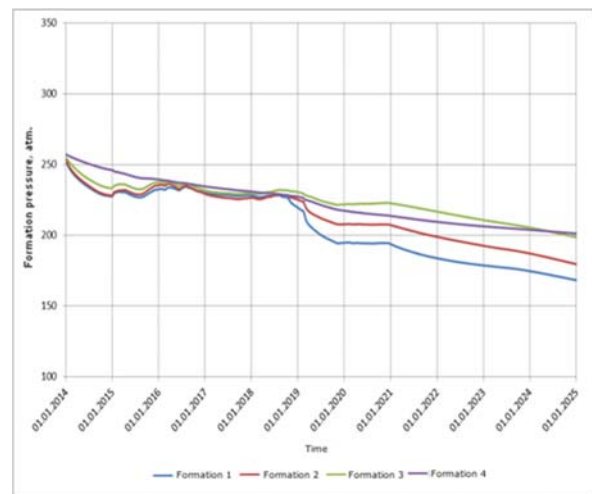

Figure-7. Formation pressure dynamics depending on the formations (increase of occurrence depth) during recovered gas re-injection.
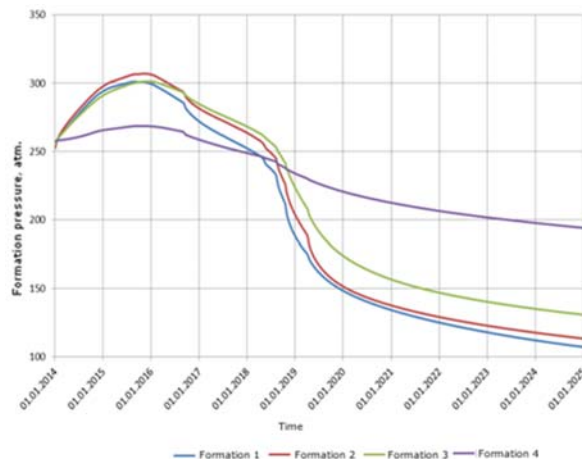
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Figure-8. Formation pressure dynamics depending on the formations (increase of occurrence depth) during nitrogen re-injection.

5. CONCLUSIONS

In the course of the numerical experiments on simulation of the development process of low-permeable reservoir during injection of gaseous agents in the system of horizontal wells with the multistage HF, a fundamentally new approach to solution of composite simulation problems with local double medium was implemented to allow accounting the peculiarities of filtration in a formation to a greater extent.

In formations with average permeability less than $0.005mcm^2$ and higher inconsistency of a formation, generally, the development system using water injection, even with high degree of treatment, is less effective than injection of gas agents. According to the simulation results, it was determined that gas injection can potentially increase the final coefficient of oil extraction in comparison with flooding. Not only the gas agent itself, but also position of the horizontal well in relation to the formations opened by hydraulic fractures exerts impact on the efficiency of the stimulation technique.

ACKNOWLEDGMENT

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