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Substantiation of the recovery of residual oil from low-productive and heterogeneous formations in Western Siberia by improving the waterflood system using gas and water-gas impacts

A S Valeev[1], Yu A Kotenev[2,3], V Sh Mukhametshin[4] and Sh Kh Sultanov[2,3]

[1]TPE “Povhneftegaz” LLC “LUKOIL–Western Siberia” 40, Shirokaya St., Kogalym, Tyumen region, Khanty-Mansi Autonomous Area – Yugra, 628482, Russian Federation
[2]Ufa State Petroleum Technological University, 1, Kosmonavtov st., Ufa, Republic of Bashkortostan, 450062, Russian Federation
[3]Academy of Sciences of the Republic of Bashkortostan, 15, Kirova St., Ufa, Republic of Bashkortostan, 450008, Russian Federation
[4]Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation

E-mail: vsh@of.ugntu.ru

Abstract. The article substantiates the conditions for effective water and gas impact on productive formations of the Upper Jurassic and Achimov deposits of the Vyintoy oil field: for the UJ formation, alternate injection of “wet” gas and water (gas injection for 3 months – water injection for 3 months) with a maximum intake capacity of gas injection wells of 15 thousand m^3 per day with a total volume of gas agent injection of 20 % of the pore formation volume; for the Ach formation, continuous injection of “wet” gas with a maximum intake capacity of gas injection wells of 30 thousand m^3 per day.

1. Introduction

Analysis of the hydrocarbon reserves structure of Kogalym region indicates a high proportion of hard-to-recover reserves (HRR) (more than 60 % for the main productive objects) due to low-permeable, heterogeneous, undersaturated, thin, highly developed formations with residual oil.

Residual oil reserves from heterogeneous formations of Western Siberia can be recovered using their own energy potential by improving the waterflood system based on the detailed study of anisotropy and modeling the flood displacement process. [1–8]

The most interesting development experience was observed at the Povkhov field characterized by highly heterogeneous and clinoform formations, the Vatyegan field with a high variation of reservoir properties (RP) of productive formations due to significant facial variability, the Vyintoy field with a complex structure of formations, pronounced uneven interlacing of sandstones and aleurolites with collectors represented by sandstone lenses and structural-lithological traps.

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2. Methods

The combined analysis of geological field data and indicators, namely, maps of distribution of cuts and oil reserves, as well as graphs of the dynamics of water production and average fluid and oil output rates per well made it possible to determine effective impacts of injection wells on production ones. The most optimal location for the AV_{1-3} reservoir of the Vatyegan field is location of injection wells in the low-productive zones, and that of production wells - in the highly productive zones.

To identify causes of the uneven development of oil reserves of the Ach reservoir group (Achimov formation) of the Vyintoy field, distribution of geological technological parameters and the energy state taking into account all direct formation pressure measurements were analyzed. The pressure distribution over the reservoir indicates its decrease in areas not covered or poorly covered by the waterflood system. Given the characteristics of the geological formation structure associated with the gradual clay formation and its pinching out, a more intensive system for maintaining reservoir pressure is required.

The study of the geological profile of the UJ_1 productive formations and its reservoir properties, the analysis of the development system being implemented made it possible to assess the state of oil reserves development. Features of the structure and differences in filtration-capacitive properties of the formations caused different well productivity and oil reserves development levels. The anticipated development of reserves and formation flooding occur in the roofing part of the section (UJ_1^1 formation). Reserves development is hindered by a high degree of formation discontinuity and numerous cases of UJ_1^2 formation water invasion. This indicates a complex structure of distribution of residual reserves due to characteristics of the geological structure and FCPs of the formation. Development characteristics and t indicators in the drilled part indicate the need for measures to improve the efficiency of oil reserves development.

3. Results and discussion

Using the UJ_1 formation of the Vatyegan field as an example, the formation anisotropy effect on the flooding coverage rate for various locations of production and injection wells was studied. The location of wells has to take into account the analysis results for the stress-strain state of the formation and its lateral heterogeneity. It is assumed that it is necessary to locate the rows of injection wells or to orientate area development systems in accordance with minimal lateral directions. This assumption was substantiated and verified on the basis of the hydrodynamic model.

In the hydrodynamic model, formation anisotropy was simulated by different permeability along the x and y axes.

Calculation results for the row development system with a ratio of permeabilities Kx / Ky = 3, Kx / Ky = 1/3 and for greater anisotropy or permeability contrast at Kx / Ky = 10 and Kx / Ky = 1/10 are presented in Figure 1. The results of calculations showed that the displacement front is more uniform when the row of injection wells coincides with the direction of maximum permeability (minimum stress).

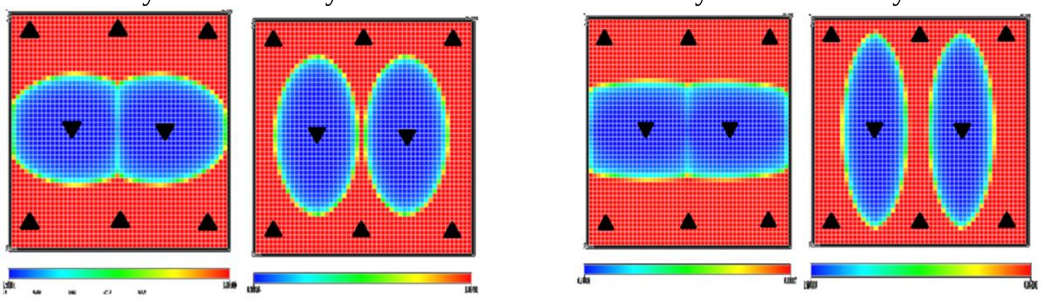
It has been established that water breaks into the production wells at a favorable ratio of injection wells occurs almost one and a half times later. If we assume that the final coefficient of oil recovery can be observed after pumping three pore volumes of the formation, the “correct” location of the wells allows an increase in oil recovery by 3 %.

For the five-point development system, well locations on the sides of a square oriented along the formation anisotropy and at an angle of 45 degrees to the formation anisotropy were analyzed. As can be seen from Figure 1, water breakthrough into the production wells at a favorable ratio of injection wells occurs almost two times later.

The studies allow for conclusion that consideration of the lateral anisotropy of permeability and directions of minimal stress in the formation increases the efficiency of the displacement process due to an increased coverage of the waterflood formation. This increases the duration of anhydrous oil production and the final oil displacement coefficient.

Calculation results for the row recovery system
at the ratio of permeabilities

Kx/Ky = 3 and Kx/Ky = 1/3 Kx/Ky = 10 and Kx/Ky = 1/10



Calculation results for the five-point recovery system
at the ratio of permeabilities

Kx/Ky = 3 and Kx/Ky = 1/3 Kx/Ky = 10 and Kx/Ky = 1/10

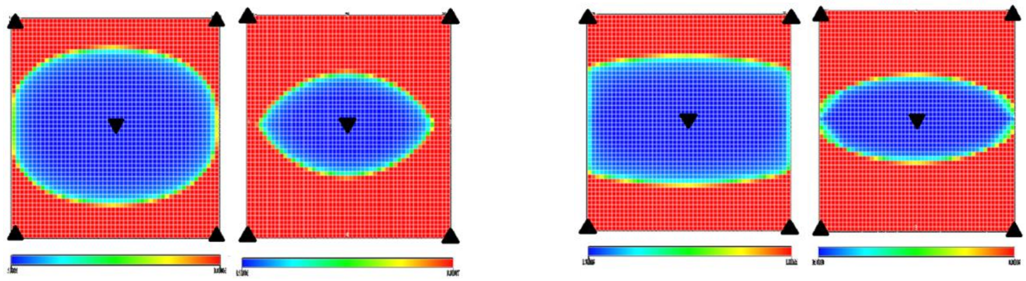


Figure 1. Studies on the influence of formation anisotropy on the waterflood coverage rate for various locations of production and injection wells of the UJ_1 formation of the Vatyegan field.

Experimental and theoretical studies carried out in Russia and abroad have shown that effective methods for enhancing oil recovery are based on the injection of gas and water-gas mixtures into the formation. [9–14] Such geological and physical factors of the oil fields in Kogalym region as low density and viscosity, relatively large depths of deposits, availability of gas resources, fine-grained polymict reservoirs with a high specific surface area and high water saturation determine the development of these technologies.

To use various approaches and technologies, it is necessary to justify them by comparing various options using a digital hydrodynamic model for determining an optimal technological mode and an impact method (Figure 2).

Comparison of the main technological development indicators for various options are presented in Tables 1 and 2.

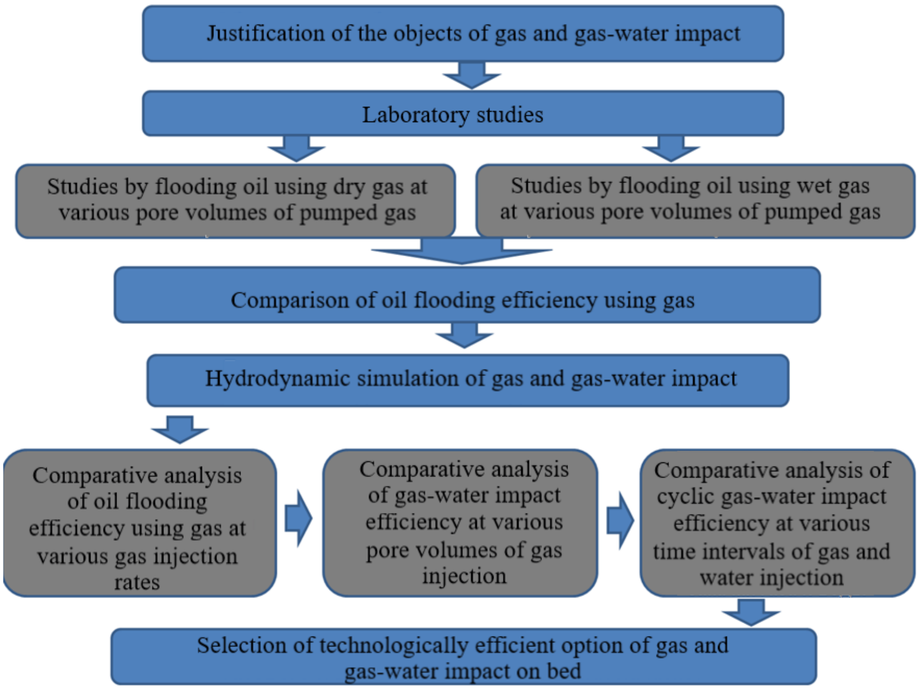


Figure 2. Methodology for the justification of the gas and water-gas impact on the oil deposits of the Vyintoy field.

Table 1. Comparison of the main technological indicators of the most effective options for the UJ formation development.

Performance indicators	Option A	Option B	Option C	**Option D**	Option E
	Basic	20%PV	30%PV	**3/3**	6/6
Cumulative oil production, thousand tons	714.89	923.9	927.1	**971.4**	954.7
Accumulated water injection, thousand m^3	2252.3	2131.7	1917.9	**1880.2**	1844.1
Accumulated gas injection, mln m^3	0	251.9	378.8	**338.5**	342.8
Development period, years	22	36	42	**22**	25
The final ORI for the site, u.f.	0.409	0.541	0.542	**0.568**	0.559

Table 2. Comparison of the main technological indicators of the most effective Ach formation development options.

Performance indicators	Option B average annual gas injection is 30 thousand m^3 per day	Option C cyclic injection is 12/12 (months)	Option A Basic
Cumulative oil production, thousand tons	**3307**	3241	2323
Accumulated water injection, thousand m^3	**1979**	8521	9909
Accumulated gas injection, mln m^3	**3594**	1798	0
The final ORI for the site, u.f.	**0.584**	0.572	0.410

Comparative analysis of gas and water-gas impacts for the UJ and Ach formations of the Vyintoy deposit showed that the largest ORI is

– 56.8 % for the UJ formation. It can be achieved under alternate injection of associated petroleum gas and water (gas for 3 months – water for 3 months) with a maximum intake capacity of gas injection wells of 15 thousand m^3 per day;

– 58.4 % for the Ach formation. It can achieved under continuous gas injection with a maximum intake capacity of gas injection wells of 30 thousand m^3 per day.

4. Conclusion

The efficiency of line-drive and five-point development systems was identified under the location of a number of injection zones in zones with maximum permeability (minimum stress) and at a permeability ratio in production and injection wells of 10: 1. For the productive formation at the Achimov deposits, the permeability ratio is 3:1.

Conditions of effective water-gas and gas impact on productive formations in the Upper Jurassic and Achimov deposits of the Vyintoy oil field were determined: for the UJ formation, alternate injection of "wet" gas and water (gas injection for 3 months – water injection for 3 months) with maximum intake capacity of gas injection wells of 15 thousand m^3 per day with a total volume of gas agent injection of 20% of the pore formation volume; for the Ach formation, continuous injection of "wet" gas with a maximum intake capacity of gas injection wells of 30 thousand m^3 per day.

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