Analysis of the development of BS10 oil reservoir at the Savuyskoye field

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Abstract. Based on the analysis of oil production at the BS10 formation of the Savuyskoye field, the article provides the calculation and justification of the necessary filter permeability which limits sand production in the well during operation of wells with weakly cemented unstable reservoirs.

1. Introduction
The Savuyskoye gas and oil field is located in the eastern part of the Surgut oil and gas region of the Central Ob region of the West Siberian oil and gas province. The commercial oil content was established in the sediments of the Sortymsky Formation of the Upper Valanginian age of the Lower Cretaceous System (BS10 formation).

The BS10 reservoir is elongated in a Northwest direction and occupies most of the licence area. The deposit is fully developed by production wells. BS10 reservoir reserves are represented by two categories - A and C2. Initial oil reserves (category A) of the BS10 formation, listed on the State balance sheet, are: geological - 109 942 thousand tons, recoverable - 50 523 thousand tons, oil recovery factor - 0.460.

The object is at the last stage of development. We are interested in the issue of its development in order to determine the residual reserves.

2. Materials
Since the beginning of development, 48 897 thousand tons of oil have been produced at the field. With a current water cut of 96.3%, the oil recovery factor is 0.393 of the approved recoverable reserves of the BC1 categories, and the production of initial recoverable reserves is 94.2%.

The BS10 formation provided 99.7% of the extracted oil (48 764 thousand tons). The production of initial recoverable reserves for the BS10 facility is 96.5% with a water cut of 96.6%, the current recovery factor is 0.444.

In the US2 formation, the degree of reserves development is low, the production of initial recoverable reserves is 9.8%.

Three sites of experimental program were organized at the US2 formation. Thus, the immediate prospect of further development of the field is associated with the low-productive formation US2.
3. Methods
As of January 01, 2018, studies on monitoring the development of oil reserves in the BS10 reservoir by production logging methods were carried out in 403 wells, including 285 production, 112 injection and 6 control wells. Based on the results of studies of production and injection wells, the parameters of the formation development were determined:

- working thickness coefficient - the ratio of the working thickness to the effective oil-saturated perforated formation thickness (determined by temperature logging and flow metering);
- coefficient of secondary completion - the ratio of the effective perforated thickness to the total effective oil-saturated formation thickness;
- coefficient of sweep efficiency - the ratio of the working thickness to the entire effective oil-saturated formation thickness;
- waterflood thickness ratio - the ratio of the waterflood thickness to the entire effective formation thickness.

In production wells, 81% of the effective oil-saturated thickness of the formation was perforated. Incomplete secondary completion of the formation is associated with the lack of reliable impermeable sections at the OWC level and the presence in the bottom of the formation of individual productive lenses that were not tapped by perforation (well No. 357, etc.). Fluid is recovered throughout the entire effective thickness. The coefficient of the working thickness of the reservoir is 1.15. The sweep coefficient over the thickness of the BS10 formation varies in the range from 0.64 to 1.0 with an average value of 0.94. The effective oil-saturated thickness of the BS10 formation in the studied wells varies from 1.8 m (well No. 702) to 26.2 m (well No. 316) and averages 11.8 m.

The current oil-saturated thickness of the BS10 formation (as of January 01, 2018) varies from 0.7 m (well No. 738) to 9.4 m (well No. 563) and averages 4.1 m. The source of watering the production of wells is the passage of the front of the injected water and pulling of formation water to the perforation interval from the bottom water-saturated part of the formation in the marginal zone.

The state of the current water flooding of the BS10 reservoir thickness is shown in Figures 6-9, plotted for different sections of the reservoir. The development of oil reserves takes place over almost the entire oil-saturated thickness with the leading flooding of the bottom part of the thickness by the water injected. The work does not involve individual low-permeable intervals of the reservoir and non-perforated lenses. The high stratification and variability of the thickness of the reservoir over the area of the reservoir is also reflected in the sweep coefficient, which, as noted above, varies from 0.64 to 1.0.

The results of testing the control wells by carbon-oxygen (C/O) logging show that the development process covers almost the entire thickness of the BS10 formation. The highest displacement coefficient is mainly observed in the bottom of the formation.

In control wells No. 817K, 818K, 820K, the data of carbon-oxygen (C/O) logging show a decrease in the oil saturation coefficient over the entire oil-saturated thickness. In July - October 2003, the BS10 formation in these wells was perforated. An inflow of oil with water was obtained in the wells, with a water cut of 80 - 93%.

High water cut of well production is confirmed by the results of C/O logging.

According to the results of C/O logging as of September 6, 2017, the BS10 formation in the control well No. 813K was oil saturated and in October 2017 it was perforated. For two months, the well operated with practically anhydrous products (water cut - 3.3%). As of September 2006, 51.8 thousand tons of oil was produced from it with a water cut of 80%. At the time of the secondary completion of the BS10 formation in well No. 813K, its surrounding wells No. 318, 387, 506, worked with a water cut of 91% - 98%. That is, in the area of these wells, a “water finger” formed and without tapping the BS10 formation in well No. 813K, it would be difficult to extract the bypassed oil formed in its area.

In exploratory well No. 4251P, drilled in November 1998, the weighted average oil saturation coefficient of the BS10 formation was 47.3%. Nearby production wells No. 270, 594, 595 at that moment were operating with a water cut of 90% - 93%.
Figure 1. The production profile of the reservoir BS10 along the line of wells №№ 447-468

Figure 2. The production profile of the reservoir BS10 along the line of wells №№ 326-459
Figure 3. The production profile of the reservoir BS10 along the line of wells №№ 859-848

Figure 4. The production profile of the reservoir BS10 along the line of wells №№ 211-237
**Figure 5.** The production profile of the reservoir BS10 along the line of wells №№ 407-206

**Figure 6.** The production profile of the reservoir BS10 along the line of wells №№ 427-441
The cumulative oil production in well No. 270 amounted to 377 thousand tons, and in wells No. 594, 595, respectively, 66.4 thousand tons and 36.2 thousand tons. In the area of the above wells, a certain “water finger” formed.

The reservoir receives the injected water within the effective oil saturated thickness. Perforation tapped 91% of the oil-saturated thickness of the reservoir. The coefficient of working thickness varies in the range from 0.15 to 1.0 with an average value of 0.9. 82% of the oil-saturated thickness of the reservoir is involved in the displacement process.
In general, the development of oil reserves in the BS10 formation is uneven both in thickness and in area. Based on the results of studies of production, injection and control wells, a map of the current oil-saturated thicknesses of the BS10 formation is constructed. The average oil-saturated thickness of the formation varies from 0.7 - 9.4 m with an average thickness of 4.1 m. The maximum current oil saturated thicknesses are identified in the southwestern part of the reservoir. Residual oil reserves are concentrated in the roofing of the reservoir and non-perforated lenses. The areas with the highest density of oil reserves are promising for sidetracking.

Figure 9. Example of allocation of inflow intervals of the reservoir BS10 for well № 517

4. Conclusions
The main development target at the Savuiskoye field is BS10, both in terms of geological reserves - 88% of the total in the field and in cumulative oil production - 99.7%. The BS10 formation is at its final, fourth stage of development. As of January 01, 2018, 48763 thousand tons of oil were recovered, which is 96.5% of the initial recoverable reserves, with a water cut of 96.5%. Oil production in 2017 amounted to 303.5 thousand tons at a rate of recovery from initial recoverable reserves of 0.6%. The current oil recovery factor is 0.444. The implemented system of the BS10 reservoir development is a three-row system of well location dividing the reservoir into 13 production blocks. The maximum values of both current and cumulative oil production are characterized by blocks 8-12, in which a significant part of the area is a water-free oil zone. The development of reserves for the blocks is uneven. Current oil recovery factors of the blocks vary in the range 0.140 - 0.632 with a change in water cut of 98.5% - 95.5%. The nature of watering in all blocks is identical - a rapid increase in produced water. However, current oil recovery factors differ by 2–3 times. By the magnitude of the current oil recovery factor and the intensity of pumping, operational blocks can be combined into three groups. Group 1 (operational blocks 5, 6, 8, 9, 12). The degree of pumping of the blocks of this group is 1.712 - 2.013 of the oil-saturated volume of the formation. The blocks are characterized by maximum values of the current oil recovery factor (0.632 - 0.481). The maximum oil recovery factor (0.632) was obtained in block 12 with a maximum degree of pumping of 2.013. Group 2 (operational blocks 4, 7, 10, 11). With a change in
The degree of pumping in the range of 1.416 - 1.545, the current oil recovery factor for the blocks varies from 0.379 to 0.447. Group 3 (operational blocks 1, 2, 3, 13). All blocks of this group (except block 13) are located in the water-oil zone. The smallest value of the current recovery factor is obtained for the regional block 1 - 0.140. The maximum oil recovery factor in this group does not exceed 0.304 (block 2). In recent years, a characteristic feature of the process of developing the reserves of the BS10 formation is an increase in the pumping rate, which in turn at the late stage of the development of the formation sharply increases the value of the current WOR. With a close degree of water cut of all blocks (about 96%), the degree of development of reserves of the selected groups of blocks differs significantly.

The difference in the intensity of development of reserves for these groups of blocks is noted at all stages. When the pumping factor reaches 0.5, they differ by a factor of 1.5–3, while the difference in the values of the accumulated WOR is 3-4 times. An increase in oil recovery factor with an increase in pumping from 0.5 to 1.0 of the pore volume in the blocks of group 3 is almost two times lower than the growth rate for the blocks of group 1. The separation of the blocks according to the intensity of development of reserves is largely due to the share of water-oil zone in the block area, the reserves and the number of active wells. The current water cut of extracted products by blocks varies from 95.5% to 98.5%.

The effective oil-saturated thickness of the BS10 formation in the studied wells varies from 1.8 m to 26.2 m and averages 11.8 m. The current oil-saturated thickness of the BS10 formation (as of January 01, 2018) varies from 0.7 m to 9.4 m and averages 4.1 m. The source of watering the production of wells is the passage of the front of the injected water and pulling of the formation water to the perforation interval from the bottom water-saturated part of the formation in the marginal zone.

The figures show examples of the allocation of working and water flood intervals of the reservoir in production wells according to well logging data. The development of oil reserves takes place over almost the entire oil-saturated thickness with the leading flooding of the bottom part of the thickness by the water injected. The work does not involve individual low-permeable intervals of the reservoir and non-perforated lenses.

The high stratification and variability of the thickness of the reservoir over the area of the reservoir is also reflected in the sweep coefficient, which, as noted above, varies from 0.64 to 1.0. The results of testing the control wells by carbon-oxygen (C/O) logging show that the development process covers almost the entire thickness of the BS10 formation. The highest displacement coefficient is mainly observed in the bottom of the formation. In general, the development of oil reserves in the BS10 formation is uneven both in thickness and in area. The maximum current oil saturated thicknesses are identified in the south-western part of the reservoir.

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