Features of localization of remaining oil in terrigenous reservoirs and potential for their recovery at the final stage of field development

Vyacheslav Sh Mukhametshin¹, Lyubov Kuleshova¹, Rustem Yakupov¹, Rif Vafin¹, and Ruslan Gilyazetdinov¹

¹Institute of Oil and Gas FSBEI of HE "Ufa State Petroleum Technological University", (Branch in the City of Oktyabrsky), 54a, Devonskaya Street, Oktyabrsky, Republic of Bashkortostan, 452607, Russia

Abstract. The paper considers one of the unique fields in terms of geological reserves. The paper also analyzes the development of the D3ps formation sections of the Devonian terrigenous layer of the studied field. A detailed geological and hydrodynamic model was constructed based on the consolidation of all available information. An integrated analysis of actual well performance data, field geophysical tests, geological and technical measures, results of infill drilling, as well as geological and hydrodynamic modeling confirmed the localization of reserves primarily in the upper bed of D₃ps₁. The analysis of all performed studies revealed higher values of current oil saturation in the upper bed – up to 0.8 unit fractions and lower values in the lower bed – up to 0.68 unit fractions. Similar results were obtained from 87 sidetracks. Drilling of wells and sidetracks is proposed in areas with no well stock. Despite the final stage and high degree of field development, the proposed strategy will support oil production levels, increase remaining recoverable reserves, increase the efficiency of reserve recovery and improve the economic performance of field development. The introduction of modern development technologies, approaches to the analysis and monitoring of development will increase the target value of the final recovery factor from 0.608 to 0.613 unit fractions, which, with a significant amount of in-place reserves, made it possible to increase the remaining recoverable reserves by 35%. The strategy will make it possible to achieve higher oil recovery rates. The approaches used to solve the tasks set in the study can be applied to the fields of the Volga region.

1 Introduction

It is known that a number of oil fields have a long production history. In some cases, based on the generalization of development process indicators this makes it possible to draw certain conclusions and project possible directions in the development of oil targets and
reservoirs with similar reservoir and fluid properties [1-8]. The paper considers one of the unique fields in terms of geological reserves.

In the middle Devonian, the Ardatsky-Vorobyevsky, Ardatsky and Mullinsky horizons are commercially oil-bearing in the section of the field, in the terrigenous Upper Devonian – the Pashiisky horizon, in the carbonaceous Devonian – the Middle Famennian subtier and the Zavolzhsky superhorizont, in the Lower Carboniferous – carbonate deposits of the Tournaisian stage and the Alexinsky horizon, as well as the terrigenous deposits of the Bobrikovian horizon.

Most of the initial recoverable reserves are associated with Devonian deposits, in which 83% of the field reserves were concentrated. Currently, the field is in the final stages of development, terrigenous targets have a high degree of reserve recovery. The carbonate targets of the field have significant potential in terms of geological and engineering operations at oil and injection well stock.

The Pashiisky horizon is at the final stage of development, oil production is decreasing, development is carried out with high water cut, the well stock is decommissioned due to the economic limit. At the same time, the remaining reserves are significant, but their development requires a set of measures.

The purpose of the study is to increase the degree of development of reserves by summarizing the indicators of the long history of field development and assessing the possibilities of introducing modern oil recovery methods. Therefore, the main tasks at the current stage of field development are as follows: localization of remaining oil in place, assessment of the efficiency of geological and technological measures (GTM), development of enhanced oil recovery strategy, and expansion of the detailed targeted program of geological and technical measures in the context of the complex geological structure of the field [9, 10].

2 Methods and materials

The development target D3ps includes both formations of the Pashiisky horizon and is at the final stage of development. It was drilled in a loop rows of wells with a distance of 500x400 m. The area is maximally covered by drilling, and the well spacing is 25.1 hectares. The object development system was improved with the continuous development of the reservoir pressure maintenance system, and the organization of out-contour flooding with the transition to focal flooding. To date, a focal-selective system for reservoir pressure maintenance (RPM) has been formed in combination with the out-contour system.

The development of the above system with the transformation of the RPM system made it possible to maximally cover the area of the object by development, take 98% of the initial recoverable reserves, and achieve an oil recovery factor of 0.594 unit fractions. The improvement of the development system ensured high sweep efficiency of 0.877 unit fractions. The high efficiency of approaches to the development of this object made it possible to replicate the accumulated experience to objects with a similar geological structure. In this regard, the greatest prospects for the localization of remaining reserves are associated with their search by section and the use of various technologies for the recovery of remaining reserves [11-12].

3 Results and Discussion

A detailed geological and hydrodynamic model was constructed based on the consolidation of all available information. An integrated analysis of actual well performance data, field geophysical tests, geological and technical measures, results of infill drilling, as well as
geological and hydrodynamic modeling confirmed the localization of reserves primarily in the upper bed of D_{3ps.1}. An example of the oil saturation cube from the hydrodynamic model is shown in Figure 1.

The field reserves are controlled by a wide range of field geophysical studies, including flow metering, thermometry, and pulsed neutron-neutron logging (PNNL). The analysis of geophysical studies revealed that in case of joint operation of the target formations, the upper one is characterized by a lower degree of involvement in the development compared to the lower one, which has better reservoir properties. Thus, in 45% of studies of production and injection wells, the work of the D_{3ps.1} formation is not noted, while in wells with the presence of inflow from both formations the share of inflow from D_{3ps.1} is lower than from D_{3ps.2-3}.

![At the beginning of development](image1)

![Current state](image2)

**Fig. 1.** Comparison of initial and current oil saturation cubes from the hydrodynamic model.

The field has a transit well stock to assess the current oil saturation, which is about 70 wells. In total, 86 studies were performed at the object using the pulsed neutron-neutron logging. As an example, Figure 2 shows the area under development since 1963 using waterflooding.

Both formations were perforated in production and injection wells. Despite development and active injection, pulsed neutron-neutron logging in 2017 and comparison with post-drilling results in well 1894 in 1968 established the presence of remaining reserves for the upper D_{3ps.1}.

Based on the analysis of all studies performed, there are higher values of current oil saturation in the upper formation – up to 0.8 unit fractions, and lower values in the lower formation – up to 0.68 unit fractions. Similar results were obtained from 87 sidetracks. The study results are summarized in the Table 1.

The change in the current oil saturation in the formations from the initial saturation shows a greater change in the lower formation, which indicates a higher recovery rate of reserves in the lower formation compared to the upper one. The degree of reserve recovery in the lower D_{3ps.2-3} is 99%, in the lower D_{3ps.1} – 86%. Currently, more than 75% of remaining oil reserves are concentrated in the upper formation, which development requires to develop and implement a complex action plan.
Fig. 2. Example of a section with remaining recoverable reserves in D3ps.1 based on the PNNL data.

Table 1. Study results based on PNNL and sidetrack drilling.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Initial oil saturation factor, unit fractions</th>
<th>Current oil saturation factor according to:</th>
<th>Change of current oil saturation compared to initial one:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PNNL</td>
<td>Sidetrack drilling</td>
</tr>
<tr>
<td>D3ps.1</td>
<td>0.83</td>
<td>0.52</td>
<td>0.80</td>
</tr>
<tr>
<td>D3ps.2-3</td>
<td>0.89</td>
<td>0.49</td>
<td>0.68</td>
</tr>
</tbody>
</table>

The designed model made it possible to clarify the localization of reserves in both the area and the section, and to develop the action plan to improve the efficiency of reserve recovery. It is planned to drill horizontal wells (HW), horizontal sidetrack (HS), perform hydraulic fracturing (HF), repair and insulation works (RIW), perforation measures. Drilling of wells and sidetracks is proposed in areas with no well stock. At the same time, it should be noted that the additional development of reserves provides for the formation of a differentiated injection system for D3ps.1 and D3ps.2-3, including additional focal flooding. Drilling operations were performed at the D3ps Shkapovskoye oil field with similar geological and physical characteristics. Work [13] shows that the efficiency of horizontal wells is determined by the rate of water flooding of the well production and the specific reserves in the preroofed part of the formation.

Despite the final stage and high degree of field development, the proposed strategy will support oil production levels, increase remaining recoverable reserves, increase the efficiency of reserve recovery and improve the economic performance of field development. The introduction of modern development technologies and approaches to the analysis and monitoring of development will increase the target value of the final oil recovery factor (ORF) from 0.608 unit fractions in 2011 to 0.613 unit fractions in 2020, which, with a significant amount of in-place reserves, made it possible to increase the remaining recoverable reserves by 35%. At the same time, the rate of extraction from remaining recoverable reserves during this period remained at the level of 5% due to the growing dynamics of oil production. The implementation of the developed strategy for further development will allow maintaining the growing trend of oil production over the
next 15 years with the achievement of the maximum production since the beginning of the 2000s.

The use of the above approaches to increase the development of reserves can be applied in the fields of the Volga region, which are at the late stage of their development.

4 Conclusion

- Innovative approaches to the development of the Pashinskiy horizon of the considered field ensured the achievement of the current oil recovery factor of 0.594 unit fractions, which was unprecedented earlier for the region. The replication of this experience into objects with a similar geological structure made it possible to achieve a recovery factor from 0.477 to 0.592 unit fractions.
- An integrated analysis of actual well performance data, field geophysical tests, geological and technical measures, results of infill drilling, as well as geological and hydrodynamic modeling confirmed that more than 75% of remaining reserves are localized in the upper bed of D3ps.1.
- A strategy for further field development was developed, including a targeted action plan for the production stock, the organization of a differentiated injection system by zones taking into account the necessary volumes of surface development.

The strategy will allow achieving higher oil recovery rates and improving the technological indicators of the field development. The approaches used to solve the problems can be applied to the fields of the Volga region.

References

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