Effect of lithological heterogeneity of bitumen sandstones on SAGD reservoir development

E A Korolev¹, S A Usmanov¹, D S Nikolaev¹ and R R Gabdelvaliyeva¹
¹Institute of Geology and Petroleum Technologies, Kazan Federal University, Kazan, Russia

E-mail: sausmanov@gmail.com, nikolaevcd@gmail.com

Abstract. The article describes the heavy oil field developed by the SAGD method. While development planning all the heterogeneity of the reservoir is must be taken into account. The objective of this work is to identify the distribution of lithological heterogeneities and their influence on oil production. For this reason, the studies of core samples were conducted and the heterogeneity was identified. Then properties and approximate geometry of lithological objects were studied. Also the effect of the heterogeneity on the heat propagation and production of fluid were analyzed. In the end, recommendations were made for the study of such heterogeneities on other deposits with similar geology

1. Introduction

Russia is rich in heavy oil and natural bitumen reserves, which are in a stepwise process of commercial development [1]. One of the production project sites of hydrocarbons difficult to recover are the Ufimian bitumen fields in the southeast of Tatarstan. The heavy oil and bitumen reservoirs are currently being developed, which pay zones occur at a shallow depth (50-200 m). One of the primary methods of heavy hydrocarbon recovery is the steam-assisted gravity drainage (SAGD). At sites, the steam simulation consists of injecting steam through a pair of horizontal wells so creating a steam chamber and warming up the reservoir layer to reduce the viscosity of the oil. The main difficulty to control this process is the uneven distribution of heat between the wells and the leakage of steam out of the chamber [2,3].

To understand the possible geological reasons for such negative phenomena, detailed lithological and mineralogical tests of wells were carried out on one of the heavy oil reservoir in the Republic of Tatarstan. The uplift chosen as a test target is one of the bar features forming the ridges stretched along the coast of the Permian paleosea of the Ufimian age [4,5,6] (Fig. 1). Considering the morphology and arrangement of ridges in the paleorelief, the bars and barrier islands are assumed to have been formed on shallow terraces where the underwater ledges of the seabed developed. The area seems to rise slightly for a short period during the formation of the Sheshma upper unit thus resulted in the stabilization of the shoreline, which ensured a long-term processing of detrital material under the conditions of active shallow-water hydrodynamics. As a result, clay siltstones and sandstones underlying the bar structures were replaced by well-sorted fine-grained sands building up underwater shafts and above-water islands. Underwater wave breaking and bottom migration of sediments contributed to a local increase in the thickness of sandstones within bar features, to improve lithological homogeneity and grading of their detrital material. This produced the
accumulative forms of the coastal-offshore relief. The subsequent transgression of the Permian paleosea changed the conditions of sedimentation, which resulted in the deposition of mostly clay material in the "lingual clays" unit. The thick "lingual clay" drapes overlapping the Sheshma sand unit became a kind of regional screen allowing oil deposition in sand bars during the upward migration of water-oil fluids. Eventually, oil deposits transformed into heavy oils and bitumen due to oxidation processes.

2. Methodology

The core analysis showed that the hydrocarbon deposits within the studied uplift are confined to well graded sandstones composing the bar body. The underlying clay-calcareous sandstones and siltstones are only pigmented with oil. The bitumen deposit is around 20 m thick in the dome of the structure.

![Figure 1. Map of heavy oil and bitumen field distribution in the Sheshma horizon bar deposits in Tatarstan.](image)

The bitumen reservoir is lithologically represented by greywacke sandstones [7]. The optical microscopic tests show that the detrital component accounts 70-85% and cemented material accounts 15-30% in the rock. The allothigenous assemblages are dominated by rounded fragments of siliceous and effusive rocks while the subrounded grains of quartz, angular grains of albite and microcline, chlorite flakes, rare rounded carbonate fragments are less presented. The fractional composition of sandstones is dominated by grains 0.1-0.25 mm in size, the silt and pelitic grains are in subordinate amounts. The fragments of rocks and minerals are cemented by argillo-calcareous and bituminous cement. The mineral cement (10-15%) of pore-lining and vein-cluster types having a micro-fine-grained texture, and the
bituminous cement (85-90%) is a pore-lining cement. A relatively small amount of argillo-
calcareous cement causes the incoherent texture of sandstones within the bitumen reservoir. If
the bitumen substance is removed, the open porosity of the rock is 15-30 %. At the same time,
it tends to reduce to 10-12 % as it approaches the bottom of the productive portion of the
bitumen reservoir. The X-ray computed tomography shows the communicating pores evenly
distributed in the rock volume are 30-80 μm in effective size [8].

Studying the mechanical properties of the sandstones of the examined heavy oil reservoir
revealed rocks featuring poor structural bonds. Almost throughout the entire bitumen
reservoir, their compressive strength is 1.25-2.75 MPa, the tension strength is 0.05-0.11 MPa,
the bond strength between mineral grains is 0.21-0.45 MPa, the Protodyakonov scale of
hardness accounts up to 0.3 MPa (Category VII).

Similar lithologic-petrographic features of bitumen sandstones show a good heat carrier intake
capacity of the terrigenous reservoir. Theoretically, considering the differences in reservoir
pressure (0.4-0.5 MPa) and injection pressure (2.0-2.5 MPa), the injected water vapor should
be relatively well and uniformly distributed between the two wells and up-dip producing a
cylindrical high-temperature steam chamber. However, the well logging data show that the
propagation of the heat carrier is difficult in some cases [2].

When handling the core samples, it was noted that a consolidated interval (10-50 cm) occur
among the medium- and semi-consolidated bitumen-saturated sandstones (Fig. 2). At certain
hypsometric levels, they can be traced in several wells drilled in different parts of the uplift,
that is, they exhibit an area distribution pattern, but not traceable in the well logging data due
to the insufficient resolution of the latter [9]. Optical-microscopic and XRD tests have shown
that all such layers are formed by tightly cemented sandstones. And, if the allothigenic
component is almost identical to those of soft sandstones in composition and ratio of mineral
fragments in the rock, the composition and texture of cement differ significantly. Secondary
basal-pore carbonate cement occurs in tight layers, which is also a cement that fills secondary
pores (completely fills all pores). Unlike the micro-fine-grained cement of soft sandstones, the
cement within the consolidated sandstone interval is uniform, fine and medium-grained in
texture. Some intervals are dominated by calcite in the mineral composition of cement, while
in the others – by dolomite. The porosity of tight sandstone does not exceed 6 %. These are
predominantly subcapillary pores.
Figure 2. Productive interval core of well 171 with consolidated sandstone interval (red line).

The results of the geological core description and the core studies were then used to build the surface of the consolidated sandstone interval top. The wells of this interval were selected for the further analysis (Fig. 3) followed by the A-B line using the saturation cube (Fig. 4).

Figure 3. Top of consolidated sandstone interval map.
The preliminary paleostructural analysis has revealed the tendency of spreading the consolidated sandstone interval according to the bottom of the Sheshma bitum bearing interval. The interval occurs below the producing well with regard to the pairs of horizontal wells 10-11 – 50-51. In the area of pairs of horizontal wells 60-61 – 80-81, the interval crosses the space between the producing and injection wells.

The following technological parameters of the development were analyzed: cumulative production of liquid and oil, steam injection volumes, oil/steam ratio (O/S), water cut (WC) (Table 1). The production and injection data are normalized on a scale of 1-10, where 10 is the maximum production/injection in the present range.

| WELL PAIR | OIL PRODUCED | WATER PRODUCED | LIQUIDS PRODUCED | STEAM INJECTED | WC  | O/S | MEAN TEMP, °C | INJECTION PERIOD, DAY |
|-----------|--------------|----------------|------------------|----------------|-----|-----|--------------|-----------------------|
| 10-11     | 6.6          | 8.4            | 8.3              | 8.5            | 0.95| 0.07| 70           | 242                   |
| 20-21     | 3.2          | 7.1            | 6.8              | 7.6            | 0.97| 0.02| 41           | 349                   |
| 30-31     | 4.1          | 5.1            | 4.9              | 5.5            | 0.97| 0.04| 83           | 170                   |
| 40-41     | 10.0         | 8.0            | 10.0             | 6.8            | 0.94| 0.14| 96           | 303                   |
| 50-51     | 4.6          | 4.0            | 4.0              | 4.6            | 0.93| 0.09| 83           | 180                   |
| 60-61     | 1.2          | 6.7            | 6.3              | 7.4            | 0.99| 0.02| 51           | 303                   |
| 70-71     | 0.4          | 6.1            | 5.7              | 9.3            | 0.99| 0.01| 39           | 297                   |
| 80-81     | 1.1          | 9.9            | 9.4              | 10.0           | 0.99| 0.01| 33           | 377                   |

With a glance to the relatively smooth distribution of flow parameters calculated by well logging data that were captured between these two wells, one of the factors affecting well performance figures is the presence and location of the above-mentioned consolidated sandstone interval in the vicinity of the wells.

Following the analysis of the accumulated development figures, preliminary conclusions were made about the possible effect of the consolidated sandstone interval on the development parameters given in Table 1.
Where the interval occurs between the pair of wells being a production and an injection well, the effect of decreasing the effective vertical permeability of the reservoir as a decrease in the oil production rates, is visible.

3. Results and Discussions

Wells Nos. 60 and 70 separated from the respective injection wells by the consolidated sandstone interval, demonstrate low efficiency and considerable water cut. In addition, despite the significant volumes of injected steam, these wells are less heated in the perforation zone against the well pairs 10-11, 30-31, 40-41 and 50-51. The possible reason of this effect could be the vertical heterogeneity of the section due to the presence of a low-permeability interval that impedes the propagation of heated oil and condensed fluid from the upper part of the formation where the steam chamber [10] is formed to the production well. The temperature drop can be caused by the displacement of the drainage area of the production well to the lower interval of the reservoir saturated with formation water having a low temperature. In this case, the heat propagation is guaranteed mostly by conductive heat transfer and the hindered communication of the heated upper interval and the production well in this area can cause a reduced performance efficiency of the well pairs 60-61 and 70-71. It should be noted that the considered effects supposedly take place in the pair of wells 80-81, however, one cannot ignore the reduced oil-saturated thickness of deposits near the wells 80-81 (Fig. 4).

The well performance analysis (Table 1) show that the steam-oil ratio is higher for well pairs 40-41, 50-51 and 10-11. This parameter can be used to assess the efficiency of a particular pair of wells. Among these high-performance wells, the pair of wells 40-41 is characterized by a significant amount of injected steam and an extensive oil-saturated thickness, which is likely to cause good performance of the well. These parameters for the other two high-performance pairs of wells (50-51 and 10-11) can be described as moderate, but production wells in these pairs are not much higher than the consolidated sandstone interval (Fig. 4). It is assumed that one of the effects that may occur due to the presence of a consolidated sandstone interval below the horizontal production well may be the limitation of water inflow into the production well from the underlying water-saturated units. Moreover, the effects of downward oil flow below the production well are under consideration. These effects should have a positive effect on well pairs 50-51 and 10-11.

4. Conclusions

Since the consolidated sandstone intervals are hard to distinguish in the bitumen reservoir using well logging techniques and surface surveys due to their small thicknesses, it is proposed to consider the propagation of the heterogeneous zones based on core tests when planning the trajectories of paired horizontal wells. Taking into account a similar geological history of the heavy oil and bitumen reservoir development in Tatarstan, similar effects can occur in other reservoirs recovered by injecting steam into the reservoir. The allocation of heterogeneity intervals, i.e. represented by consolidated sandstone, similar to that considered in this paper, should be performed at the stage of the general study of the reservoir and the results should be counted in order to construct more detailed geological models.

The work was supported by the Ministry of Education and Science of the Russian Federation (project No. 02.G25.31.0170) and by the subsidy allocated to Kazan Federal University as
part of the state program for increasing its competitiveness among the world’s leading centers of science and education.

References
[1] Danilova, Ye.A. Heavy Oil in Russia // The Chemical Journal. – 2008. – No. 12. – p. 34-37.
[2] Sudakov, V. Technology of Integrated Monitoring of Steam Chamber Evolution During the Oil Production from the Shallow Deposits of Super-Viscous Oil / Sudakov V., Nurgaliev D., Khasanov D., Stepanov A., Khamidullina G., Kosarev V., Galukhin A., Usmanov S., Zarirov A., Amerkhanov M. // Paper SPE-182000-MS presented at the SPE Russian Petroleum Technology Conference and Exhibition, 24-26 October 2016, Moscow, Russia. http://dx.doi.org/10.2118/182000-MS
[3] Makarevich, V.N., Iskritskaya, N.I., Bogoslovsky, S.A. Resource Potential of Heavy Oil Reservoirs in the European Russia // Neftegazovaya Geologiya. Teoriya i praktika. – 2012. – T. 7, No. 5. – p. 27–32.
[4] B.V. Burov. Geology of Tatarstan. Stratigraphy and Tectonics – M.: GEOS, 2003. – p. 402.
[5] Petrov, G.A. Lithological and Facial Analysis of the Upper Permian Bitumen Reservoirs Related to the Assessment of Bitumen Resources Within Tatarstan: Author's abstract. Thesis Work by Candidate of Geological and Mineralogical Sciences. – Kazan, 2000. – p. 27.
[6] Khasanov R.R., Mullakaev A.I., Dusmanov E.N. The structure of sandstones in productive horizons of the Permian bituminous deposits of Tatarstan (Russia) // Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki. – 2017. – Vol. 159, № 1. – p. 164–173.
[7] Mullakaev A.I., Delev A.N., Usmanov S.A., Sudakov V.A., Khasanov R.R. Tectonic causes of uneven cementation zones distribution in the bituminous sandstones productive part of the Sheshmian horizon of the South Tatar arch // Neftyanoe Khozyaystvo - Oil Industry. – 2018. – №2. – p. 23-25.
[8] Zakirov, T.R., Galeev, A.A., Korolev, E.A., Nuriyev, I.S., Statsenko, E.O. Estimation of sandstone reservoir properties using X-ray CT studies in Ashalchinskoye oil field // Neftyanoe Khozyaystvo - Oil Industry. – 2015. – № 8. – p. 36-40.
[9] Nikolaev, D.S. Studying the Geological Features of the Primary Pay Zones of Heavy Oil Reservoirs in Tatarstan // West Siberian Petroleum Congress: a collection of scientific papers of the XI International Scientific and Technical Congress of the Student Department of the Petroleum Engineer Society / Editor-in-chief S.I. Grachyov; TIU. – Tyumen: TIU, 2017. – p.169. ISBN 978-5-9961-1461-0
[10] Butler R.M. Horizontal Wells or the Recovery of Oil, Gas and Bitumen // Petroleum Society Monograph No. 2, 1994.