Shale oil in Bazhenov formation on deposits of Western Siberia

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Abstract. The Bazhenov shale, the unique object of concentration of nonconventional reserves of hydrocarbons, is the main petromaternal rock of the central part of the West Siberian lowland. It is traced practically in all its territory, both by seismic cuts, and according to correlation schemes of wells’ cuts. According to some experts’ estimates, about 15% of oil resources in Western Siberia occur in siliceous and clay rocks of the Bazhenov shale, where at the beginning of 2016 more than 90 fields with inflow of oil from clay rocks are registered. Owing to high inhomogeneity of the layer, low filtrational and capacitor properties, high water repellency, geological and other features, the Bazhenov shale on Western Siberia fields either has not been developed, or oil production conducted as trial tests. The main goal of this article is the presentation of researches’ results and development of the Bazhenov shale on two perspective fields of Western Siberia.

1. Introduction

Bazhenov formation refers to unconventional oil and gas reservoirs. Fabian Gurari opened it as a subsuite in Maryanovsky suite in 1959. It was first discovered near Bazhenovka village in Omsk district in the Russian Federation.

Bazhenov formation lies at a depth from 1 to 3.5 kilometers on the territory of Western Siberia. It was formed by marine sedimentary rocks with complicated mineralogical composition in the Upper Jurassic – Lower Cretaceous period. The major rock-forming components were clay mine (25-30%), silicates (35-60%), carbonate minerals (8-12%) and solid organic substances, kerogen (10-20%) (A.N. Shandrygin, I.V. Shpyrov, V.G. Bratkova, 2015). Layer thickness is on average 35 meters, the area of distribution is 1.2 million km². According to some experts’ assessments, the siliceous-argillaceous rock of Bazhenov Formation contains about 15% of oil resources in Western Siberia (I.I. Nesterov, 1987). At the beginning of 2015, more than 90 fields with influx of oil from clay rocks were registered.

Today, there are a number of unresolved issues relating to both reserves’ estimation and selection of efficient technologies of oil extraction from the source rock of Bazhenov Formation. The current oil recovery factor is very low, no more than 5-7%. However, the major oil companies such as Surgutneftegaz, Rosneft and Lukoil, where main Bazhenov oil reserves are concentrated, create the efficient production technologies and the first steps in this direction have been already made.

Experimental-industrial development of Bazhenov formation is conducted in Upper-Salymskoe, Salymskoe, Mid-Nazymskoe, Galyanovskoe, Maslikhovskoe, Kamynskoe, Krasnoleninskoe, Syneganskoe, Ulyanovskoe, West-Sakhalinskoe, Murynauskoe, Alehinskoe and Ai-Pimske fields at
2. Results and Discussion

Ulyanovskoe field

The development of Ulyanovskoe field was an interesting experience, where the Bazhen Formation was put into operation in 2005. At the beginning of 2014, five horizontal wells with the open hole and one exploration well were drilled. The main objective of experimental-industrial development was to develop the technology of reservoir opening on depression by underbalanced horizontal wells installation "Continuous tube". Wells №1000Gr, 1001Gr, 1002 1003Gr, 1004Gr were put into operation. Drilling-in was performed at minimum reservoir repressing using biopolymer drilling mud. Selected deposit opening technology provoked a manifestation of complications during drilling, particularly in sinking of the plantar portion of formation. In this regard, full drilling-in of Bazhen Formation was performed only in two wells, No1000 Gr and No 1001 Gr (Table 1).

Table 1. Borehole posting parameter with reservoir and exploration results

| Well number | Start-up date | Horizontal | Vertical | Penetration through the formation, m | Net oil pay of the zone, m | Oil rate, t/d | Cumulative oil production, thous. t | Current well condition |
|-------------|---------------|------------|----------|-------------------------------------|--------------------------|-------------|-----------------------------------|------------------------|
| 1000 Gr     | 06.2005       | 140        | 31       | 31                                  | 30.1                     | 3.3         | 8.2                               | 24.2                   |
|             |               |            |          |                                     |                          |             | Well works through the collapse of the precipitate |
| 1001 Gr     | 09.2006       | 290        | 30       | 31                                  | 17.6                     | 4.3         | 10.4                              | 27.1                   |
|             |               |            |          |                                     |                          |             | Well works through the collapse of the precipitate |
| 1002 Gr     | 03.2006       | 116        | 16.1     | 31                                  | 2.5                      | Idle since 08.2008 | 1.6                        | 1.5                    |
|             |               |            |          |                                     |                          |             | New wellbore since 12.2009         | Gas outlet since 08.2011 |
| 1003 Gr     | 10.2006       | 75.3       | 5.3      | 31                                  | 16.7                     | 5.1         | 5.8                               | 11.8                   |
|             |               |            |          |                                     |                          |             | New wellbore filter since 11.2010  |
| 1004 Gr     | 09.2006       | 84.9       | 12.3     | 31                                  | 1                        | Idle since 08.2008 | 1.6                        | 0.9                    |
|             |               |            |          |                                     |                          |             | Wellbore collapsed                |

In 2006 and 2007, the current fund was 5 wells with the horizontal oil production in this period amounted to 9.1 and 8.8 tons, respectively. In 2008 and 2009 only 3 wells were productive, with annual production hardly decreased and amounted to 9.2 and 7.8 tons, respectively. In 2010, four wells produced 8 tons. During the period under review, development of water cut has increased slightly...
from 1.7 to 7.9%. An average flow rate of oil increased to 10.4 tons/day in 2010. In the period from 2011 to 2013, the active wells fund was 5 units. In 2013, the average flow rate of producing wells totaled: oil – 5 tons/day, liquid – 5.3 tons/day (Table 2).

While operating in wells, the horizontal unfixed portion of the bore collapsed. Wells operated through precipitate collapse with a primarily productivity loss (wells №1002Gr, 1004Gr) and with the gradual silting up of the sediment as the collapse result (well №1003Gr) was represented by large scraps. In wells №1000Gr and 1001Gr, the cyclic change in production rates over time was observed during the operation process; its decrease was replaced by a sharp increase. This behavior can be explained by silting of collapse and, while pressure increases down the hole, the limited selection of partial purification of oil from the small mineral-organic product took place.

### Table 2. Development indicators of Bazhenov formation of Ulyanovskoe field at the beginning of 2014

| Date   | Extraction, thous. t | Water-cutting, % | Oil rate, t/d | Current producing wells | Operation time of production wells, d |
|--------|----------------------|------------------|---------------|-------------------------|---------------------------------------|
|        | Current | Accumulated | Current | Accumulated | Current | Accumulated | Oil | Liquid | Current | Accumulated |
| 2005   | 4.286   | 4.286     | 0.075   | 0.075       | 4.361   | 4.361       | 1.72 | 24.49  | 24.92   | 1           | 175  |
| 2006   | 9.057   | 13.343    | 0.310   | 0.385       | 9.367   | 13.728      | 3.31 | 10.61  | 10.97   | 5           | 854  |
| 2007   | 8.845   | 22.188    | 0.352   | 0.737       | 9.197   | 22.925      | 3.83 | 5.86   | 6.09    | 5           | 1509 |
| 2008   | 9.185   | 31.373    | 0.621   | 1.358       | 9.806   | 32.731      | 6.33 | 6.05   | 6.46    | 3           | 1519 |
| 2009   | 7.793   | 39.166    | 0.354   | 1.712       | 8.147   | 40.878      | 4.35 | 8.76   | 9.15    | 3           | 890  |
| 2010   | 8.008   | 47.174    | 0.684   | 2.396       | 8.692   | 49.570      | 7.87 | 10.37  | 11.26   | 4           | 772  |
| 2011   | 6.752   | 53.926    | 0.438   | 2.834       | 7.190   | 56.760      | 6.09 | 5.81   | 6.18    | 5           | 1163 |
| 2012   | 6.107   | 60.033    | 0.487   | 3.321       | 6.594   | 63.354      | 7.39 | 5.47   | 5.90    | 5           | 1117 |
| 2013   | 5.471   | 65.504    | 0.382   | 3.703       | 5.853   | 69.207      | 6.53 | 4.95   | 5.30    | 5           | 1105 |

Oil production from the beginning of development increased to 65.5 thousand tons, including well №1001Gr – 27.1 thousand tons (41.4% of the total production) and well №1000Gr – 24.2 thousand tons (36.9% of the total production volume).

4 hydraulic fractures were conducted in 3 wells, two of them in existing production well №1004Gr (including one repeated) and two at the construction stage in wells №1001Gr and №1003Gr. 24.01 tons of oil were additionally produced due to the hydraulic fractures. The average weight of proppant injection during the hydraulic fracturing in the wells was 16.6 tons.

There was a 1.4-time magnifying flow rate of fluid (oil) after the first hydraulic fracturing in existing production well №1004Gr. The flow rate of fluid (oil) increased slightly from 1.9 (1.8) tons/day to 2.6 (2.5) tons/day. Watering hole production has increased from 1.6% to 2.7%. In January of 2007, repeated hydraulic fracturing was conducted in the well, proppant injection mass increased from 4.2 up to 15 tons, but a positive result was not obtained. After the hydraulic fracturing, the flow rate (oil) decreased from 2.8 (2.5) tons/day to 1.8 (1.8) tons/day. The water content of wells decreased from 10.1% to 1.6%. As of 01.01.2011, the well operated with a flow rate of fluid (oil) equal to 2.0
(1.0) tons/day and water cut – 50%. After two hydraulic fractures in well No1004Gr, additional production was not received.

Due to hydraulic fracturing in two producing wells (№1001Gr, 1003Gr), 24 thousand tons of oil were additionally produced, while the current specific efficiency was 12 thousand tons per operated well. An average oil production growth in these wells increased to 5.6 tons/day and the expected specific efficiency was estimated as 18.13 tons per operated well. In general, the success of hydraulic fracturing for 4 conducted operations was 50%.

The experience on Ulyanovskoe field proves the ineffectiveness of the wellbore end as an open face because of collapse of its loose parts. At the same time, the work on the EMG, held in the collapse of the trunk, was unsuccessful. Hydraulic fracturing conducted in a borehole cased by a slotted filter was of low efficiency. Making deepenings and side holes as well as drilling new horizontal wells showed greater efficiency, but in this case, the collapse of the barrel could not be avoided either.

**West-Sakhalinskoe field**

Bazhenov formation on the territory of West-Sakhalinskoe deposits opened 23 search, 13 exploration and 7 production wells. The pilot commercial operation of horizontal and directional wells began in 2009. In total, in this section, 13 wells were drilled, four wells (No110, 114, 115 and 5559) are inclined, one (No102 GR) is horizontal with sinking on a layer of 69.8 m and a volume hydraulic fracturing, four wells (No101Gr, 104Gr, 107Gr, 111Gr) are horizontal with the open hole wells and five (No 103Gr, 105Gr, 109Gr, 112Gr, 113Gr) are horizontal with a slotted liner on the bottom and volume hydraulic fracturing.

The shaft collapsed in all four horizontal wells with the opened down hole and wells operated through precipitate of collapse with an output of about 1 ton/day. Thus, horizontal wells with the opened down hole proved to be ineffective. In this regard, in wells №101Gr and 107Gr an additional directional sidetrack was drilled to conduct hydraulic fracturing proppant and pumping about 50 tons per well. Considering the events in 2011, well №101Gr was put into operation with the oil production rate of about 16.2 tons/day. Further, the oil production rate decreased to 9 tons/day in 2012 and up to 8 tons/day in 2013. At the beginning of July 2013, the cumulative oil production for well №101Gr was 5.9 tons. Well №107Gr has not been put into operation even after all conducted measures at the beginning of 2013.

Horizontal wells were more productive with down hole overlapped by a slotted filter and with conducting in them the hydraulic fracturing with pumping of proppant of about 40 tons per well (except for well №113Gr). The hydraulic fracturing was performed twice in wells №109Gr and 112Gr. Well №103 was the most successful among them. It was put into operation in January 2011. In the first three months of oil production its average yield was 23.7 tons/day, but by March 2012, its value had declined to 0.8 tons/day, after which the hydraulic fracturing was carried out in the well. The oil flow rate after the hydraulic fracturing was 78.7 tons/day. The cumulative production for this well at the beginning of 2013 amounted to 20.5 thousand tons and it continues to work with the oil production rate of 56.6 tons/day and 2.5% of water cut. Remaining four wells, including those in which hydraulic fracturing was conducted twice, have significantly worse results. Input flow rates in them during the first three months ranged from 1.0 to 4.4 tons/day. Yields production rates increased to the range from 2.8 to 18.4 tons/day after hydraulic fracturing. The total cumulative oil production amounted to 9.4 thousand tons from these four wells at the beginning of 2013, which was twice less than that one of the 103rd well.

Horizontal well №102 GR with sinking on a layer by 69.8 meters was put into operation in October 2009, after carrying out in it the hydraulic fracturing with injection of 60 tons of proppant. An average production rate of the well was 12.5 tons/day in the first three months. Subsequently, its output has dropped to 2.6 tons/day by May 2012, and then there was second hydraulic fracturing with injection of 40 tons of proppant. However, this allowed one to increase the production rate of only 0.2 tons/day. After 30 months of operation of the well at the beginning of 2013, the current oil production rate was 2.1 tons/day with cumulative production of 6.2 tons.
Further, let us consider the history of exploitation of four directional wells. Wells №110 and 115 did not differ. They were commissioned in 2009 and 2010. The hydraulic fracturing was also conducted there. It was held twice in well №110. Thus, 50 tons of proppant was pumped for the first time and 100 tons - for the second time. The oil flow rate after fracturing was 17.5 tons/day. Cumulative production for this well amounted to 6.2 thousand tons and for well №115 it was only 2.0 tons at the beginning of 2013. Well №5559 has the lowest operational history of all wells. It was launched in October 2012 with the input rate of 7.1 tons/day; and in July 2013, its yield was 3.9 tons/day. Cumulative production was 1.2 thousand tons in less than a year for well №5559. The well №114 is of greatest interest among directional wells, which was commissioned in 2009 with carrying out hydraulic fracturing. The amount of injected proppant was 50 tons. The oil flow rate after exposure amounted to 122 tons/day. Further, the well was working steadily, its average oil production rate in 2010 was 80 tons/day, in 2011 – 57 tons/day, in 2012 – 22 tons/day and in 2013 - about 10 tons/day. Cumulative oil production at the beginning of 2013 for this well was 79 thousand tons, which is 1.6 times more than in the rest of the 13 wells. It is obvious that success of this well is not associated with formation of opening technology, and with a hit in a highly productive zone of fracture.

During the production period of wells, a high rate of decline was experienced in oil production rates. An average input flow rate of oil from wells amounted to 17 tons/day, after the first year of operation – 15 tons / day, after two years – 13 tons/day (22% of the initial). In the fourth year of operation, the average flow rate of oil wells, according to a single valuation date, amounted to 6 tons/day (-64% of initial).

130 thousand tons of oil was produced totally at this field in the period from 2009 to 2012, with a maximum annual production of 37.4 thousand tons in 2012. During this period, current producing wells increased from 3 to 14 units, the average oil production rate decreased from 63.4 to 9.4 tons/day, and water cut ranged from 8.2 to 4.6%.

An interesting experiment was conducted at the field, which purpose was to inject 4 m³ of water under pressure of 62.5 MPa into well №115 in September 2011; for this purpose, the artificial fractures in the layer and dissolution of gas accumulations in joints of the system were formed. Reaction to this event was noticeable in almost all wells of the field, indicating the presence of a highly heterogenetic hydrodynamic connection of the fracture system.

Within a month after injection, wells were operating at a stable flow-rate. Water injection has provoked the displacement of gas packs that are stuck in cracks of the system, which resulted in establishment of an intermittent flow to slaughter gas and oil wells (gas discharge packs). Restoring a relatively basic level of oil production from the land occurred after 6 months (loss of oil production amounted to 7.6 thousand tons for this period) after measures of urging the inflows (washing the borehole and down hole with hot oil wells, hydraulic fracturing wells №101Gr, 103Gr, 105Gr).

Such results clearly indicate the formation of an artificial fracture in formation and displacement of gas accumulations. However, formation of the resistant and viscous water and oil emulsions in the system of cracks had temporarily a negative impact on the productivity of surrounding wells and required incentive influx methods.

Thus, results of wells’ operation on West-Sakhalinskoe field are confused. An average production rate was 17 tons / day when the range of input flow rates of oil was from 0.9 tons/day to 122.3 tons/day. An input flow rate of oil of more than 10 tons/day was produced in four out of 14 drilled wells on the given area. The rate of decline of productivity in the first years of operation of the well was 10-50% (for both directional and horizontal wells). Current oil production rates vary from 0.7 tons / day to 56.6 tons / day with an average of 8.3 tons / day. Three wells with daily output of more than 10 tons / day out of 13 existing wells were operated. Well 114 demonstrates the greatest efficiency having a directional profile with volume hydraulic fracturing conducted by the special technology.

To improve the effectiveness of the Bazhenov Formation development in Western Siberia, it is necessary to address the following issues: quality improvement technology and trouble-free construction of wells in the conditions AHFP and predisposition to destruction of rocks in boreholes; improvement of existing and creation of new development technology, recovery and increasing in the
productivity of wells in relation to the conditions of Bazhenov Formation; creation of a regulated educational technology in formation of a dense network of fracture; improvement and development of new technologies for fracturing wells of various types, excluding rupture cracks output of formation and clogging the natural fractures with gel.

3. Conclusion
In the fields, where the oil from the Bazhenov formation is extracted, high accumulated production of a well should not be linked with the drilling-in technology, because the application of similar drilling-in technologies on neighboring wells does not show similar results, indicating that the existence of the highly productive fractured system, entering into which is the determining factor of success. There is a sharp variation of wells by flow rates and a significant proportion of low-rate wells, a significant decrease in well production rates over time, and as a result, very low values of cumulative oil production, as well as a minor amount of drainage layers. High-producing wells were confined to zones of fractured reservoirs, and therefore the main focus of improving the development of the system is to find those areas by various methods and involving wells into the crack system, for example multi-stage hydraulic fracturing in horizontal wells.

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