The application of thermal gas treatment of the Bazhenov formation

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Abstract. A large number of publications devoted to the oil production from the Bazhenov formation was published in the Russian scientific and technical magazines focused on specialists in development of oil and gas fields in the last 5 – 10 years. It is connected with the fact that traditional resources of hydrocarbons are gradually reduced, forcing the oil-extracting companies to pay more and more attention to shale oil which the greatest quantity in the Russian Federation occurs in the Bazhenov formation. The main objective of this paper is a review of obtained results of development of the Bazhenov formation on the Middle field.

1. Introduction
The Russian Federation has unique oil-source rocks of the Bazhenov formation. These rocks contain oil volumes that many times exceed deposits of traditional traps. Deposits of the Bazhenov formation are similar to shale oil, but the distinctive feature is that the transformation process of organic matter is not completed yet. In this regard the hydrocarbons are contained in the collector along with the light oil directly in a compound rock-forming part of rock and called kerogen. Kerogen is generally sapropelic substance which in turn is organic and mineral sediment of lake reservoirs. Organic matter is formed mainly due to the disintegration of the vegetable and animal organisms living in water, in a smaller measure – at the expense of the remains of land plants brought from the land.

2. Results and Discussion
The development experience of the Bazhenov formation on Middle field is of great interest first of all by the fact that a thermal gas method of displacement of oil from the oil and kerogen bearing rock was applied on this field. The field is located in the Ob part of the Bazhenov formation with the main characteristics consisting in alternation of the drained and not drained deposits. The quantity of the drained pro-layers can be from 3 to 5 layers with the total thickness of 25-30% from the total thickness.

Experimental programs on technology of air and water injection and also the control of this process on the pilot site of well No. 219 of the Middle field are conducted since October, 2009. Before it the oil production from 5 wells was produced in the natural recovery drive. The cumulative production was 82 thousand tons by the beginning of tests (3.8% of initial geological deposits). Reservoir pressure on the site decreased approximately to 140 bar, more, than twice than initial. Taking into account that the saturation pressure is 117 bar, the oil production potential on the natural recovery drive was almost exhausted. Air was injected periodically to the delivery well. For the beginning of September, 2013 the
accumulated air injection was about 7.3 million nm$^3$. Water injection was realized in small volumes during the periods of the termination of air injection. The cumulative water injection made 5160 m$^3$.

The lack of oxygen in the extracted gases for the entire period of test works and also the significant increase in a share of nitrogen (to 60%) and carbon dioxide (up to 70%) should be mentioned.

Air and water injection allowed restoring pressure up to 200-250 bar. in short terms. As before the production was carried out in the natural mode, the reservoir pressure was extremely quickly reduced that negatively affected on production rate of production wells. An increase in reservoir pressure is observed even near well № 3002 located in a zone with the worst filtration properties of rocks.

The development state of the first site of well №. 219

On the site chosen as the first site for the preliminary experimental test of the equipment prior to trade tests there was no regular system of influence (location of wells, the presence of a horizontal trunk with hydraulic fracturing of layer in well 401, lack of normal hydrodynamic link of well № 3002 with other wells). There were 5 wells in operation (219, 401, 3000, 3001 and 3002). All wells of the site of an uncertain and vertical profile, except for well №.401 which is with the horizontal termination of a trunk. Well №. 219 was operated by the gushing way; other wells of the site were transferred to the mechanized operation (ESP). Wells prior to influence worked at the natural mode, pressure on the site fell on average from 30.3 MPas (hard currency. № 219) up to 16.6 MPas. Well №. 219 was chosen as an injection well for ensuring of the greatest coverage of layer by the influence as it was the most productive, and had the greatest drained area.

The cumulative production was 82.4 thousand tons or 2.7% of initial geological deposits by the beginning of test works (October, 2009). At the same time the reservoir pressure decreased almost twice on the site. Therefore, the oil production potential on the natural mode up to the saturation pressure (11.7 MPas) was almost exhausted.

By the beginning of 2016 the cumulative oil production on the site makes 128 thousand tons, the average flow rate in wells of the site in 2015 made 5 tons/day, selection from initial recoverable reserves - 7.5%. The oil recovery coefficient within the pilot site made 1.5% according to the stocks which are registered on the State balance.

Well №. 219 was commissioned in April, 2003 with an initial flow rate of 107 tons/day in the gushing way. The cumulative oil production made 49.1 thousand tons. Due to the reduction of reservoir pressure in 2009 it was stopped and transferred to piesometric stock and further in 2010 it is entered into forcing. Well No. 219 is the only injection well on this pilot site, was in inaction for a cause of infringement of technical condition of a production string and the deep equipment fault. For the end of 2015 the well is liquidated.

Horizontal well №. 401 was commissioned in November, 2005 with an initial flow rate of 19.7 tons/day by the gushing way, in 2008 was transferred to the mechanized production (ESP). The well was twice transferred even to operation on a gushing way, because of impossibility to operate the well at the raised gas factor (more than 500 m$^3$/m$^3$). Since April, 2014 the well was commissioned by ESP with a flow rate of 7.8 tons/day. Pressure on the pump intake during the operation of ESP for the end of 2015 was 28-30 bar (the pump is located 500 m above the perforation interval), with wellhead and buffer pressure – 3.0 and 3.5 bar, respectively. For the beginning of 2016 the cumulative oil production makes 27 thousand tons.

In 2007 well №. 3000 with an initial flow rate of 15.5 tons/day was commissioned by the gushing way, in November, 2007 it was moved to the mechanized fund.

It was restarted by the gushing way in February, 2010, operated 16 months with an average flow rate of 2.5 tons/day. Since November, 2011 the well has operated in the mechanized way (ESP). The cumulative oil production for the beginning of 2016 makes 17.5 thousand tons. As of the beginning of 2016 the well was commissioned with a flow rate of 5.5 tons/day. Pressure on the pump intake during the operation of ESP was 30-35 bar (the pump is located 700 m above the perforation interval), with wellhead and buffer pressure – 6.5 and 3.0 bar, respectively. For the beginning of 2016 the cumulative oil production makes 27 thousand tons.

In 2007 well №. 3001 and 3002 were commissioned. Well No. 3001 was commissioned by the mechanized method (ESP) with an initial flow rate of 18.6 tons / day. The well worked stably and with
virtually no downtime over the entire period of operation. The flow rate and cumulative oil production at the beginning of 2016 is 6.9 tons/day and 27.7 thousand tons, respectively. At the end of 2015, the pressure at the pump intake during the ESP operation is 35-40 bar (the pump is located 700 m above the perforation interval), wellhead and buffer pressure are 6 and 3 bar, respectively.

Well No. 3002 was commissioned by the fountain method with an initial flow rate of 4.7 tons/day and after 3 months it was transferred to a mechanized fund. The well operates with low oil flow rates (the average production rate is 3.0 tons/day and the cumulative oil production is 6.9 thousand tons). As of the beginning of 2016, the well is in operation with a periodic operation mode and an oil flow rate of 1.3 tons/day. The pressure at the pump intake during the accumulation period is up to 50 bar, at start-up it is about 30 bar, wellhead and buffer pressures are 3.0 and 3.0 bar, respectively.

The average water cut in the wells of the pilot site is 0.8%, i.e. wells give virtually anhydrous products.

The energy state of the deposit can be estimated by the dynamics of reservoir pressure in the wells of the site. The largest cumulative oil production in the site is characterized by wells No. 219 and 3001. There is a significant decrease in reservoir pressure in the site.

**Development status of the second section: well 210**

As of the beginning of 2016, the cumulative oil production in the site is 95.9 thousand tons. The average oil flow rate of the wells in the site in 2015 was 5.1 tons/day. The recovery from the initial recoverable reserves was 4.2%. The coefficient of the oil recovery within the pilot site was 0.8% in accordance with the reserves listed on the state balance.

In the site of the well 210, there were 6 operating wells (No. 210, 3003, 3005, 3007, 3008 and 3009). All site wells have a conditionally vertical profile. The wells No. 3003, 3005 and 3007 were operated using the free-flow production method. In August 2011 they were transferred to mechanized production (ESP), the wells No. 3008 and 3009 were put into operation using the mechanized method (ESP). The well No. 210 worked in a free-flow production method before moving to the injection fund.

At this site there were two wells – No. 210 and 3003 in the injection fund.

The well No. 210 was commissioned in January 2009 with an initial flow rate of 12.5 tons/day by the free-flow production method. Cumulative oil production amounted to 7.7 thousand tons. After a period of inactivity from April 2012, it was transferred to the injection fund in June 2013. Stable operation of well No. 210 in the injection mode could not be achieved – during 2013, the well was in operation for 11 days then it was transferred to inactivity due to violation of the technical condition of the production string and shut-down of the downhole equipment and subsequently eliminated.

In October 2009, well No. 3003 was put into operation with an initial flow rate of 22.7 tons/day and the water cut of 2.4%. During the production fund period, cumulative oil production amounted to 24.8 thousand tons. In August 2013, the well was transferred to the injection fund. From October 2013 to March 2015 it was inactive due to a violation of the technical condition of the production string and shut-down of the deep equipment. Since March 2015, water and air are being pumped to test the technology of thermal gas exposure at the site in the area of the well No. 210.

In 2010, wells No.3005 and 3007 were commissioned with an initial production rate of 10 and 31.8 tons/day. At the beginning of 2016, the cumulative oil production was 2.6 and 59.6 thousand tons, respectively.

The production well No. 3009, put into operation at the end of 2011, with an initial flow rate of 1.5 tons/day of anhydrous oil, produced 0.8 thousand tons of oil at the beginning of 2016. The well is in
periodic operation with an average oil flow rate of 0.9 tons / day, the water content of the production is up to 1%

As of the end of 2015, the oil flow rate in the well was 0.5 tons / day. During operation, the average dynamic level was 1800-1900 m, at the wellhead and buffer pressures it is 4.0 and 4.0 bar, respectively.

The production well 3008 with an initial flow rate of 2 tons / day of anhydrous oil was put into operation in February 2012. The cumulative oil production at the beginning of 2016 was 0.4 thousand tons.

As of the beginning of 2016, the well was in periodic operation with an oil flow rate of 0.2 tons / day. During the accumulation period, the average static level was 1400–1600 m at low wellhead and buffer pressures – about 1.0 bar.

At the beginning of 2016, all production wells of the site were in operation. At the end of 2015, the average water cut in the wells of the pilot site was 4.1%. Well No. 3008 was working with the highest water cut.

3. Conclusion

Before turning to the main results of the first stage of field testing of the thermal gas method of development at the experimental sites of wells 219 and 3003 (210), it is necessary to identify those features of the process that have had and will further continue to affect the efficiency of the implementation of the thermal gas method of development at the testing sites.

When using the thermal gas method of development for the fields of the Bazhenov formation, the heat and gas effects are integrated and solved, including the following main tasks:

- A drastic increase in oil recovery index from the drained areas due to the in-situ transformation of the injected air into an effective mixing displacement agent and its combination with thermal-steam and hydrodynamic effects.
- Entering into the effective development of non-drained areas due to thermal effects from drained areas and its combination with hydrodynamic effects.
- Extraction of additional oil and hydrocarbon gas due to pyrolysis and cracking of kerogen in the drained and undrained areas.

It should be noted that a characteristic feature of the rocks of the Bazhenov formation is the alternation of drained and undrained sediments, with the number of 3-5 drained interlayers with a total average thickness of 20-30% of the total reservoir thickness. The alternation of drained and non-drained areas is very favorable for the organization of thermal effects on non-drained areas from drained ones. Another distinctive feature of the implementation of thermal gas exposure is that in the drained areas, kerogen, rather than heavy fractions of reservoir oil, will be used as fuel for in-situ combustion. This is explained by the fact that the content of kerogen in the carbonate lithotype of rocks of the Bazhenov formation in the Middle field is 8-10% of the volume, which is comparable with the initial content of light oil in the void space – 7-8%. Consequently, the volume of coke formed from the reservoir oil will be an order of magnitude less than the burning volume of kerogen, which is about 30-40% of its total volume.

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