

Results of research and commercial production of shale oil in Bazhenov formation on Ai-Pimskoe field

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Abstract. A large number of articles devoted to Bazhenov Formation appeared in Russian scientific and technical journals, aimed at specialists in oil and gas fields development over the last 5 – 10 years. This is due to the fact that traditional hydrocarbon resources are gradually reducing, making oil companies pay attention to shale oil; the largest deposits in the Russian Federation are in Bazhenov Formation. The main purpose of this article is to highlight results obtained during the development of Bazhenov Formation on Ai-Pimskoe field in Western Siberia.

1. Introduction

At the beginning of 2013, the highest number of cumulative oil (except for Salymskoe field) was obtained from 41 wells from Ai-Pimskoe field, that is more than 1 million 400 thousand tons, which is about 75% of cumulative oil produced from mentioned fields. Figure 1 shows the dynamics of annual and accumulated Bazhenov oil on Ai-Pimskoe and all mentioned above deposits (except for Salymskoe field).

2. Results and Discussion

Bazhenov formation on Ai-Pimskoe field is represented as a fractured cavernous type of collector with abnormally high formation pressure (AHFP). Measurements of reservoir pressure were produced by subsurface-pressure gauge during research of nine exploratory wells on transient filtering modes during sampling at the inflow. On average, initial reservoir pressure as a result of the most reliable data is taken at the level of 40.6 MPa. Reservoir temperature is about 92 °C. Total thickness of Bazhenov Formation exposed in wells at Ai-Pimskoe field ranges from 22 to 31 m, oil net pay thickness varies from 5.2 to 7.8 m. The average value of porosity as it was determined by results of 259 core laboratory studies selected from seven wells was 0.078 units. An average permeability value as it was determined by the results of 17 well test was 3.6 mD. Degassed oil examined for 41 subsurface samples and taken from 11 deep wells, has an average density of 863 kg/m³ at 20 °C and a viscosity of 15.49 mPa*s; the viscosity at 50°C on average is 5.8 mPa*s. This is brief geological and physical characteristics of Bazhenov Formation and its saturation in the oil field.

Bazhenov oil extraction on Ai-Pimskoe field has been conducted since 2000 year by two wells, prospective well № 4034 and exploration № 4021. In 2004, exploration well №4034 is in hibernation with cumulative oil production of 27.4 thousand tons, and explorational well number 4021 is operated in a fountain mode, and at the beginning of 2013 its yield was 0.77 t/day with cumulative oil



production of 44.2 thousand tons. The dynamics of existing stock of producing wells and the average flow rate is presented in Figure 2.

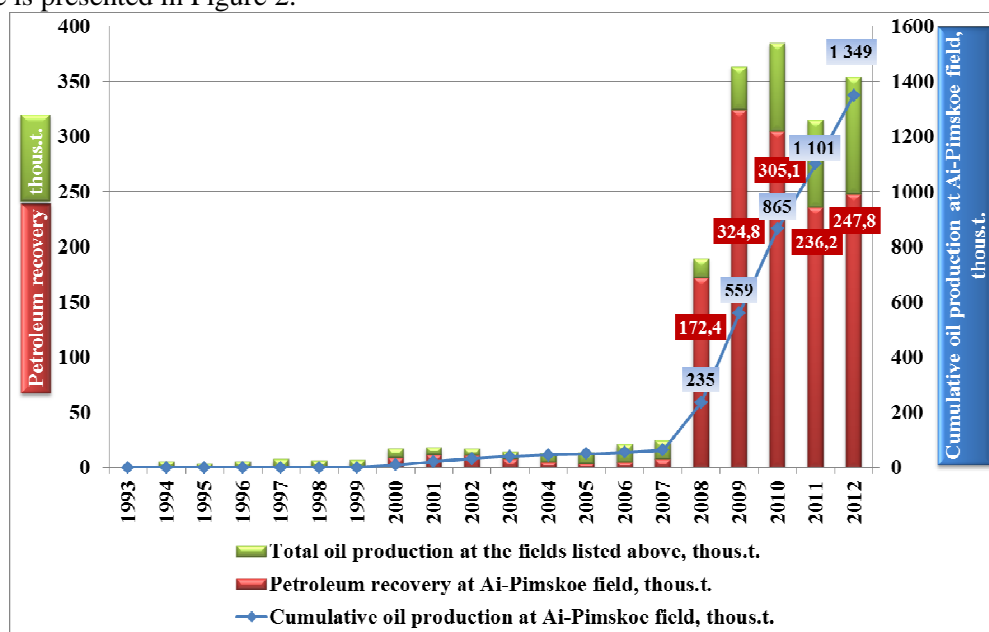


Figure 1. The dynamics of oil production of Bazhenov oil on Ai-Pimskoe and other deposits mentioned above

Further, the input history in exploitation wells drilled in Bazhenov Formation on the field will be considered. In 2007, three multi-branched horizontal wells were drilled and put into operation (№ 2, 3 and 4). In 2008, there were five wells: two obliquely-directed (№5 and 14), one horizontal (№ 6), a multi-branched horizontal (№ 10) and a prospective well (№ 4012P). In 2009, 16 wells were constructed and commissioned, including four directional wells (№ 13, 20, 22 and 29), three horizontal wells (№ 7, 12 and 26) and seven multi-branched horizontal wells (№ 8, 9, 11, 15, 19, 24 and 36). In 2010 — five wells, three of which are inclined (№ 28, 30 and 33), one horizontal (№ 31) and a multi-branched horizontal (№ 23). In 2011, only one multi-branched horizontal well was put into operation (№ 21), and in 2012, the number of wells drilled totaled 10 units, with nine of them inclined (№ 35, 37, 45, 47, 48, 50, 51, 158 and 1387) and only one horizontal (№ 32). Thus, in early 2013, from Bazhenov formation of Ai-Pimskoe fields, oil production was carried out in 13 horizontal splitters, 7 horizontal, 18 inclined and 3 exploration wells.

The operational efficiency of multilateral horizontal wells will be considered further. The maximum flow rate of oil produced by this group of wells ranges from 21 to 261 tons/day. An average oil production rate for the entire period of operation of these wells varies from 1 to 131.6 tons/day, on average, the well was producing 24.2 tons/day. The current flow rate ranges from 0.8 to 47.7 tons/day. Cumulative oil production of multilateral horizontal wells varies from 3.2 to 169.4 thousand tons, an average of 35.3 tons accounts for the well. More than 50 tons of oil from 13 wells was in three (№№ 4, 19 and 36) wells, the cumulative production of which increased to 115, 58 and 169 tons, respectively. Less than 5 tons of oil from 13 wells was also in three (№№ 8, 15 and 24) wells, the commissioning of these wells was carried out even in 2009. In six of multilateral horizontal wells out of 13, hydraulic fracturing with injection of proppant from 2 to 50 tons per well was conducted.

Horizontal wells were a little more efficient with respect to multi-branched horizontal and directional in terms of the averaged cumulative oil production per well (Table 1), but further analysis showed that, by dividing the cumulative oil production by the waste time, this group of wells showed the worst results of the averaged specific cumulative oil production. The maximum flow rate of oil produced by this group of wells varies from 2.5 to 297 tons/day. An average oil production rate for the

entire period of operation of these wells varies from 0.5 to 105 tons/day. On average for a well, it was 24.2 tons/day. The current output changes from 0 (well №6 has been stopped) to 8.4 m/day. Cumulative oil production of horizontal wells varies from 0.3 to 188 tons, an average of 40.1 tons accounting for well. Only two from seven wells have more than 50 tons of oil (№ 1 and 6). Their cumulative production amounts to 188 thousand tons and 78.2, respectively. Less than 5 tons of oil from seven wells was in four wells (№ 12, 26, 31 and 32), commissioning of which was implemented in 2009, 2009, 2010 and 2012, respectively. Four of six horizontal wells with hydraulic fracturing were performed by pumping proppant from 41 to 75 tons per well.

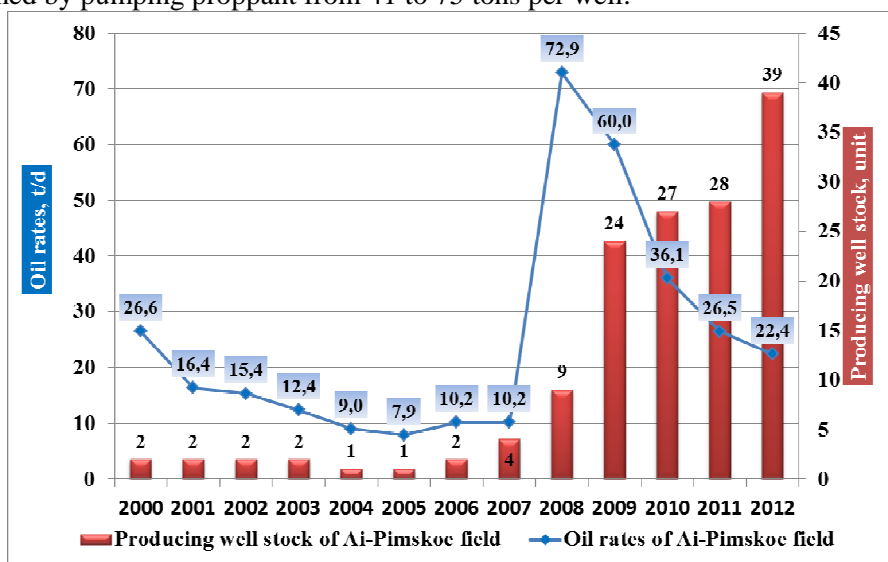


Figure 2. Dynamics of the existing stock of producing wells and their average oil production rate.

Table 1. Performance indicators of wells of various orientations

Well type	Range of the highest oil rates (t/d)	Range of the average oil rates for the entire period, t/d	Range of cumulative oil production from wells, thous. t.	Averaged cumulative oil production wells in this group thous.t	Range of spent months in the set group of wells, month	Range of specific cumulative oil production, thous. t/m	Averaged specific cumulative oil production in the set group of wells, thous. t/m
MbHW*	21-261	1-132	3.2-169.4	35.3	19-62	0.08-4.03	0.79
HW*	2.5-297	0.5-105	0.3 - 188	40.1	8-59	0.01-3.24	0.73
DW*	2.5-247.7	1.8-174.2	0.1-154.4	29.0	1- 140	0.04-5.82	1.30

MbHW – multi-branched horizontal wells

HW – horizontal wells

DW – directional wells

In inclined wells including three exploration wells, the obtained oil flow rate ranges from 2.5 to 247.7 tons/day. An average oil production rate for the entire period of operation of these wells varies from 1.8 to 174.2 tons/day, on average, well making 40.7 tons/day. The current output ranges from 0.8 to 247.7 tons/day, except for one stopped exploratory well №4034. Cumulative oil production on inclined wells varies from 0.1 to 154.4 thousand tons, an average of 29 tons per well, which is less than that of horizontal and multi-branched horizontal wells. 3 wells with the cumulative production of

116, 154 and 120 tons, respectively, were selected from 21 wells (№№ 5, 20 and 22). Eight wells were selected from 21 wells with less than 5 tons of oil (№ 30, 35, 37, 45, 48, 51, 158 and 1387), but these figures are not indicative as seven of these wells were put into operation only in 2012. In this connection, it is advisable to consider the specific cumulative production, that is, accumulated production divided by the number of working hours, for example, divided by the number of completed months of service. This will build a more objective picture of efficiency of operation of wells of different architectures. In 17 out of 18 directional wells, the hydraulic fracturing with the injection of proppant from 40 to 106 tons per well was conducted.

For more objective efficiency of the assessment of wells' operation in different fields, it is better to refer to Table 1. It is seen that the horizontal wells having worked on the average of 40.4 months per well and produced 40.1 tons per well are characterized by best figures according to averaged cumulative oil production. But as the working time in wells is different, it is advisable for each well to divide the cumulative oil production by the number of completed months of service, which will come to a more objective indicator – specific cumulative oil production. To compare different well profiles between each other, it is possible to sum specific indicators of cumulative production within each group, and divide it by the total number of wells within these groups, which will provide specific averaged cumulative oil production for each group of wells. Averaged specific cumulative oil production is nothing more than the amount of oil in tons averagely mined from the well. According to this indicator, directional wells are characterized by the most efficiency, the average cumulative production of oil in the well, which was 29 tons on the average for 33.6 months and showed the best results of 1.3 tons per month per well, despite the fact that this indicator is composed of 0.79 and 0.73 tons per month, respectively, among horizontal and multi-branched horizontal wells.

The main volume of 999.1 thousand tons of oil obtained from 8 high-producing wells № 1, 4, 5, 6, 19, 20, 22 and 36 with a maximum daily yield of 193.7 tons/day and the average one for the whole production period of well is 84.4 tons/day (Table 2). In 2012, wells № 6 and 19 due to lack of inflows were inactive, and wells № 1 and 4 were operated with an average production rate of 0.8 tons/day. Main reasons for low productivity of these wells are that in case of low reservoir pressure (25-27 MPa) in the fractured reservoir system, there is collapse of a horizontal part of the borehole, formation of mineral tubes, colmatation of the bottom-hole zone and formation of gas barriers that only in wells № 1, 6 and 19 for the period of 06/10/2010-02/02/2011 resulted in loss of about 180 tons/day in daily oil production

Table 2. Performance indicator of high-producing wells

Well number	Well type	Year of commissioning	Operating method	The maximum oil rate, t/d	Current oil rate, t/d	Average oil rate for the entire period, t/d	Cumulative oil production, thous.t.
1	HW *	2008	fountain	297.0	0.84	105.08	188.00
36	MbHW *	2009	fountain	261.4	15.23	131.65	169.44
20	DW *	2009	fountain	166.7	104.65	121.85	154.39
22	DW *	2009	fountain	209.9	95.87	90.34	119.88
5	DW *	2008	fountain	122.8	49.29	68.99	116.18
4	MbHW *	2007	fountain	170.1	0.84	63.16	114.96
6	HW *	2008	fountain	128.6	stopped	47.23	78.25
19	MbHW *	2009	fountain	193.0	0.84	47.33	58.02
MbHW – multi-branched horizontal wells				Average 193.7 t/d	Average 38.2 t/d	Average 84.4 t/d	total 999.1 thous.t
HW – horizontal wells							
DW – directional wells							

To present 7 wells with highly specific cumulative oil production will be indicative. Numbers of these wells and their indicators are presented in Table 3.

Table 3. Performance indicator of high-producing wells

Well number	Well type	Year of commissioning	Operating method	The maximum oil rate, t/d	Current oil rate, t/d	Cumulative oil production, thous.t	Average oil rate for the entire period, t/d	Specific cumulative oil production, thous.t /month
47	DW*	2012	fountain	247.7	247.74	29.09	174.21	5.82
50	DW*	2012	ECP*	161	144.23	9.87	121.85	4.94
36	MbHW	2009	fountain	261.4	15.23	169.44	131.65	4.03
20	DW*	2009	fountain	166.7	104.65	154.39	121.85	3.77
1	HW*	2008	fountain	297	0.84	188	105.08	3.24
22	DW*	2009	fountain	209.9	95.87	119.88	90.34	2.72
5	DW*	2008	fountain	122.8	49.29	116.18	68.99	2.11
MbHW – multi-branched horizontal wells				Average 209.5 t/d	Average 94.0 t/d	Total 786.8 thous.t	Average 116.3 t/d	Average 3.8 thous.t/month
HW – horizontal wells								
DW – directional wells								
ECP – Electrical centrifugal pump								

As is seen, five wells № 36, 20, 1, 5, 22 with cumulative oil production over 50 tons are also presented in Table 3. But there are two new wells № 47 and №50 that were not in Table 2 since their entry into operation was carried out only in 2012, and because their cumulative oil production has not exceeded mark of 30 thousand tons. These two wells at the beginning of 2013 perform the highest level of cumulative production of specific and current oil production, and therefore, they have all prospects to exceed the value of cumulative production of 50 or even 100 thousand tons of oil.

3. Conclusion

Thus, the results of wells' operation on the Ai-Pimskoe field are confusing. In terms of averaged cumulative oil production per well, horizontal wells have shown a little more efficiency relatively multi-branched horizontal and directional wells. However, as the further analysis proved, when dividing cumulative oil production by the working time, the worst averaged results of cumulative oil production were presented in this group of wells, according to which the best values were noted in directional wells.

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