Simulation of Interbedding Processes with Air Injection into Oil Deposits with Various Geological and Physical Characteristics

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Abstract. Thermohydrodynamic simulator STARS of software package CMG performed calculations of technological parameters of highly viscous oil deposits with various geological and physical characteristics by initiating interbedding combustion with air injection into the reservoir. Various geological and physical characteristics include the depth of deposits, initial reservoir pressure, initial reservoir temperature, and oil viscosity in the initial reservoir conditions. The results of calculations showed that changes in average temperature of the reservoir, as well as indicators of oil production depend on geological and physical characteristics of the oil deposit. In accordance with the results of calculations, depending on geological and physical characteristics of the reservoir and oil viscosity we established criteria to use electric heaters at the initiation of interbedding combustion.

Keywords: highly viscous oil deposit, geological and physical characteristics of the reservoir, thermohydrodynamic simulator STARS, horizontal well, vertical well, initiation of interbedding combustion, air injection into reservoir, oxidizer

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At present, the oil industry of Tatarstan has an urgent task of developing highly viscous, extra-viscous and bitumen oil fields. The solution to this problem is to create new industrial technologies for the development of such oil.

Thermohydrodynamic simulator STARS performed calculations of technological parameters of highly viscous oil deposits by initiating interbedding combustion with air injection into the reservoir. The air contains oxygen in its composition, which is an oxidizing agent for the development options, in which horizontal wells are used as production wells Well_gorizontal_prod. Vertical wells are used as injection wells Well lnject air, the bottomhole of which is located 28-32 m above the horizontal well and 10-15 m from its bottom toward the wellhead (Fig 1).

The main input geological and physical parameters of the model, the values of which have not changed in the calculations are given in the Table 1. Geological and physical parameters of the model input parameters, the values of which have changed during the calculation are listed in Table 2.

As can be seen from Table 2, we consider two parameters of reservoir systems, differing in deposition conditions and physicochemical properties of reservoir oil. In the first case (lines 1-6) the characteristics are listed of the oil-bearing objects with the depth not exceeding 100 m, initial reservoir pressure - about 0.45 MPa, initial reservoir temperature about 8 °C. At the same time, oil viscosity, saturating the pore space, is more than 1000 mPa·s. Examples of such objects, in particular, are Permian deposits of Ashalchinsky uplift of Ashalchinsky field and Mordovo-Karmalsky uplift of Mordovo-Karmalsky field. Such objects are attributed to the deposits of the first type.

In another case (lines 7-12) the characteristics are listed of oil objects at a depth of more than 1000 m, initial reservoir pressure over 10 MPa, and reservoir temperature of about 25 °C. At the same time, the oil viscosity at such sites does not exceed the value equal to 1000 mPa·s. The oil-bearing objects with similar geological and physical characteristics are Bobrikovian deposits of Kamishlinsky and Nurlatsky fields. These objects are attributed to the deposits of the second type.

Calculations of technological parameters of heavy oil fields by initiating interbedding combustion for all options considered were carried out until reaching of average reservoir

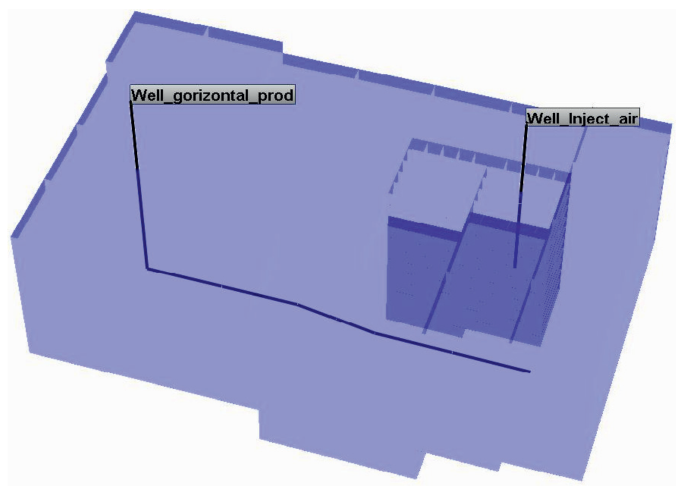

Fig. 1. Arrangement of wells (vertical that injects the air, and horizontal that extracts product) in the implementation of THAI technology.

Parameters	Layers
	Terrigenous
Type of porous reservoir	porous
Area of hydrocarbon saturation, thous. m^2	75
The average total thickness, m	14,3
Mean oilsaturated thickness, m	7,8
The average thickness of the water-saturated, m	5,1
The porosity	0,221
Oil saturation of pure oil reservoir	0,875
Permeability, 10^{-3} μm^2	893,0

Table 1. Constant values of geological and physical parameters.

Parameters / No.	Depth of formation, m	Initial reservoir pressure, MPa	The initial formation temperature, °C	Oil viscosity, MPa·s	Oil saturation	Accumulation type
1	2	3	4	5	6	7
1	80,0	0,45	8,0	1271,4	0,4	First
2					0,6	
3					0,8	
4				3449,2	0,4	
5					0,6	
6					0,8	
7	1239,5	13,00	25,0	354,9	0,4	Second
8					0,6	
9					0,8	
10				894,1	0,4	
11					0,6	
12					0,8	

Table. 2. Variable values of geological and physical parameters.

temperature on the object of the temperature on moving combustion front, ranging from 500 to 800 °C, or until the breakout of combustion gases to the horizontal wellbore Well_gorizontal_prod.

Change of interbedding temperature in the reservoir during the initiation of interbedding combustion is the most important parameter by which we can judge the nature of the process. If over time interbedding temperature rise is not observed, this is an indication that the combustion process in the formation does not occur. Achieving average reservoir temperature ranging from 150 to 300°C indicates that there are processes of low-temperature oxidation. Complete combustion process is accompanied by a significant increase in temperature. In this case only the temperature in the combustion zone can reach 400 °C or more (Baybakov, Garushev, 1977).

Changes in average reservoir temperature on all the objects under consideration are shown in Fig. 2, changes in cumulative oil production for the projects are in Fig. 3.

Analysis of the built curves for changing average reservoir temperature and cumulative oil production leads to the conclusion that in oil deposits of the second type with all initial oil saturation values full combustion process begins almost immediately after the air injection start into the reservoir. In oil deposits of the first type combustion process starts simultaneously with air injection into the reservoir for cases with initial oil saturation of 0.4 and 0.6.

However in oil objects of the first type with the initial oil saturation 0.8 when injecting air into the reservoir, there is no substantial growth of reservoir temperature. This indicates that the air injection into the reservoir at the first type deposits initiates the beginning of low-temperature oxidation process. The increase of reservoir temperature indicates the transition of the low-temperature oxidation into full combustion and is observed after a certain time after the start of air injection. Thus, with the initial oil viscosity of 1271.4 MPa growth of the reservoir temperature is observed after about 11 years, and with the initial oil viscosity of 3449.2 MPa the growth is recorded in 21 years after the beginning of the initiation of interbedding combustion by injecting air.

Thus, in all types of deposits considered the initiation of interbedding combustion processes is possible. The only difference is a shift in the start time of the combustion process, caused by geological and physical features of the occurrence,

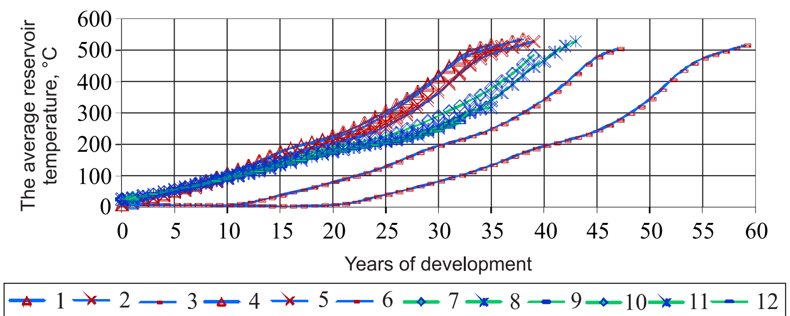

Fig. 2. Dynamics of the average reservoir temperature.
1 –deposit of the first type, oil viscosity - 1271,4 mPa·s, oil saturation –0,4;
2 - deposit of the first type, oil viscosity –1271,4 mPa·s, oil saturation – 0,6;
3 – deposit of the first type, oil viscosity –1271,4 mPa·s, oil saturation – 0,8;
4 – deposit of the first type, oil viscosity – 3449,2 mPa·s, oil saturation – 0,4;
5 – deposit of the first type, oil viscosity – 3449,2 mPa·s, oil saturation – 0,6;
6 - deposit of the first type, oil viscosity – 3449,2 mPa·s, oil saturation – 0,8;
7 – deposit of the second type, oil viscosity – 354,9 mPa·s, oil saturation – 0,4;
8 – deposit of the second type, oil viscosity – 354,9 mPa·s, oil saturation - 0,6;
9 – deposit of the second type, oil viscosity – 354,9 .mPa·s, oil saturation –0,8;
10 – deposit of the second type, oil viscosity – 894,1 mPa·s, oil saturation - 0,4;
11 – deposit of the second type, oil viscosity – 894,1 mPa·s, oil saturation - 0,6;
12 – deposit of the second type, oil viscosity – 894,1 mPa·s, oil saturation – 0,8.

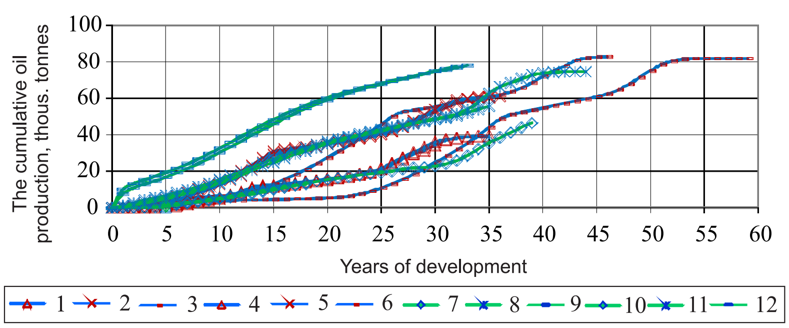

Fig. 3. Dynamics of the cumulative oil production. For the legend see Fig. 2.

rheological properties of reservoir oil, value of the initial oil saturation.

Earlier growth of the average reservoir temperature at the initiation of interbedding combustion by injecting air to oil objects of the first type can be achieved either by organizing the simultaneous air and fuel injection into the reservoir, where low viscous oil can be used (Khisamov et al., 2010), or by pre-heating the reservoir using different capacity of electric heaters (Bakirov et al., 2013).

In particular, the calculations were carried out of technological parameters at the initiation of interbedding combustion in deposits with oil viscosity of 1271.4 and 3449.2 MPa and oil saturation 0.8 using electric heaters with capacity 20 and 50 kW and operation options, providing their continuous work during the entire development period, either their shutdown in 2,6 and 12 months after the development start.

Changes in average reservoir temperature and cumulative oil production for these options are shown in Fig. 4, 5. As the graphs show, at the initiation of interbedding combustion in deposit with oil viscosity 1271.4 MPa, using an electric heater with a capacity of 20 kW it is advisable to turn it off in 12 months after the start of operation, while using a 50 kW electric heater it is sufficient to disconnect it already in 6 months after the start of operation. At the initiation of interbedding combustion in deposits with oil viscosity 3449.2 MPa it is advisable to use 50 kW electric heaters with their shutdown in 6 months after the start of operation. When using 20 kW electric heaters we can observe lagging of the average reservoir temperature and cumulative oil production from the growth of these indicators in the case of 50 kW electric heaters.

There have also been attempts to calculate developing options involving the use of electric heating capacity of 75 kW and higher. However, to carry out calculations of technological parameters for these capacity values of electric heaters could not be due to the fact that the calculations are stopped from the first steps after the launch of the problem to solve. For real field conditions it means that in conditions of these deposits application of electric heaters with higher capacity is impractical.

The given calculation results of technological parameters follow us to the conclusions.

1) At the initiation of interbedding combustion by injecting air injection into deposits with oil viscosity over 1000 mPa·s, oil saturation 0.6 and below, depths of 80-100 m, at initial reservoir pressure of about 0.5 MPa and initial reservoir temperature of about 8 °C; as well into deposits with oil viscous below 1000 mPa·s, depth of about 1100-1300 m, initial reservoir pressure of 10-15 MPa and initial reservoir temperature of about 25 °C increase in average reservoir temperature is observed almost immediately after start of air injection. In the development of such deposits by initiating interbedding combustion it is not necessary to apply additional measures to accelerate the transition of interbedding combustion process into stage of full combustion.

2) When initiating interbedding combustion by injecting air into deposits with oil viscosity over 1,000 mPa·s and oil saturation 0.8 or higher, at a depth of 80-100 m, initial reservoir pressure of about 0.5 MPa and initial reservoir temperature of about 8 °C increase in average reservoir temperature is observed through quite a long time (10-20 years) after the start of air injection. To accelerate the transition process from low-temperature oxidation to the stage of full combustion reservoir preheating must be held using electric heaters or forced organization of interbedding combustion by simultaneous injection of air and fuel into the reservoir, for which low viscous oil can be used.

3) When injecting air into all types of reservoirs with oil saturation below 0.6 in the presence of free water, wet interbedding combustion process is initiated.

4) If we select measure of reservoir preheat using electric heaters to accelerate the transition of low-temperature oxidation, the optimal recommended capacity used by electric heaters increases with the oil viscosity of developed deposits. With an increase in capacity applied the need for continuous operation of electric heaters is reduced at

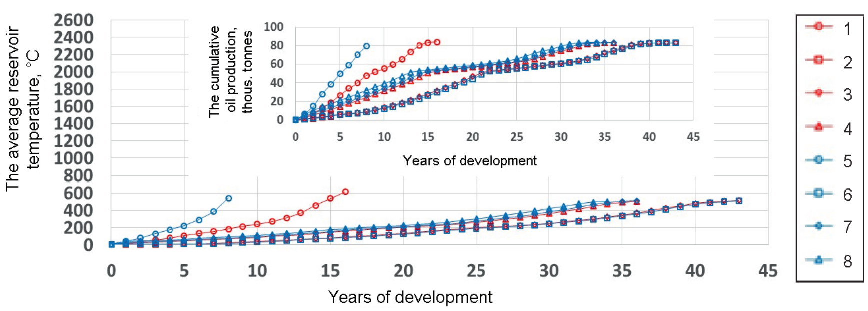

Fig. 4. Dynamics of the average reservoir temperature and cumulative oil production for various applications of electric heaters at the initiation of interbedding combustion on deposits with oil viscosity of 1271.4 mPa·s.
1 – electric heater capacity- 20 kW, continuous electric heater operation; 2 – electric heater capacity – 20 kW, electric heater shutdown in 2 month after start of the operation; 3 – electric heater capacity –20 kW, electric heater shutdown in 6 month after start of the operation; 4 – electric heater capacity – 20 kW, electric heater shutdown in 12 month after start of the operation; 5 - electric heater capacity-50 kW, continuous electric heater operation; 6 – electric heater capacity –50 kW, electric heater shutdown in 2 month after start of the operation; 7 – electric heater capacity-50 kW, electric heater shutdown in 6 month after start of the operation; 8 – electric heater capacity – 50 kW, electric heater shutdown in 12 month after start of the operation.

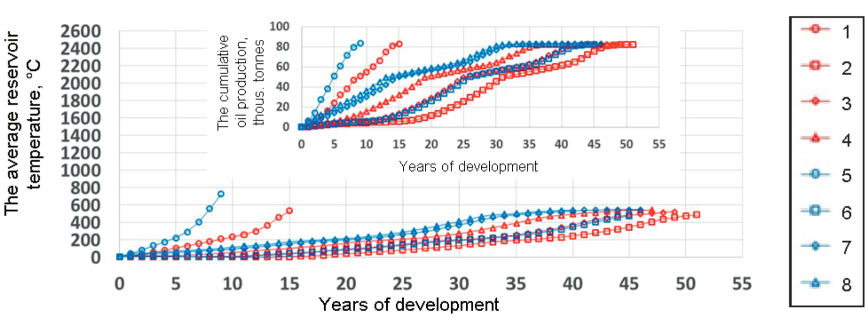

Fig. 5. Dynamics of the average reservoir temperature and cumulative oil production for various applications of electric heaters at the initiation of interbedding combustion on deposits with oil viscosity of 3449.2 mPa·s. For the legend see Fig. 4.

initiating combustion in the early development of the oil-bearing object.

5) Depending on the oil viscosity there are limits for maximum capacity of electric heaters, which can be used at the initiation of interbedding combustion by injection of air.

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