Reasons of formation of hard-to-recover reserves of Samotlorskoye field

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Abstract. Based on the analysis of geological and field data, the dynamics of indicators of development and waterflooding efficiency, a permeability-porosity and hydrodynamic model of the deposit was established, the reasons of formation of hard-to-recover reserves were revealed, and measures on the increase of oil recovery and the reduction of the volume of unproductive expenditures were substantiated.

1. Introduction

Samotlorskoye oil-gas condensate field is located in Nizhnevartovsk region of the Khanty-Mansi Autonomous District at a distance of 30 km to the north from Nizhnevartovsk city. It belongs to Vartovsk oil and gas area of the Middle-Ob oil and gas bearing area.

In the tectonic relation, the field is attributed to the group of local elevations (Samotlorskoye, Belozernoye, Martovskoye, Malosamotlorskoye, Mykhpaiskoye, Novogodneye, Bolshechernogorodskoye), complicating Nizhnevartovsk vault.

The geological section is intersected by deep wells up to 2844 m (well 8); 113 m is covered along the basement.Paleozoic basement is overlain by Jurassic, Cretaceous, Palaeogene deposits; Neogene ones are absent and Quaternary sediments of 40 m in thickness overlay the rocks of Novomikhailovsk measure (Middle Oligocene). The total thickness of the sedimentary cover amounts to 2700-2900 m.

The field was struck in 1965 with prospecting borehole 1, in which during testing bed АВ, the oil inflow was obtained with the flow rate of 163 m/day on the 8 mm connecting branch. The commercial oil-and-gas content is connected with Upper Jurassic, Neocomian, and Cenomanian-Neocomian oil and gas bearing complexes. Altogether, 78 deposits were discovered, of which 7 are gas and oil ones, 1 is a gas one, and 70 are oil deposits, timed to 27 productive strata. The majority of deposits are of stratal-arc type; some are complicated by local change in lithology and tectonic deformations.

Productive deposits are presented by sandstones and siltstones with interlayers and clay lenses. Accessible porosity varies from 13 to 29%, permeability — from 8 to 1170 mD. Oil properties change with the depth from bituminous to very light ones (0.966- 0.825 g/cm³), from high sulfur to low sulfur ones (2.17-0.6%), from low-in-tar to high-in-tar ones (4.2 – 27.7%), from low paraffin to paraffin ones (0.7-4.8%), gas factors — from 70 to 160 m³/m³. Open flow production potential is up to 160-250 m³/day. Stratal waters are chloride-calcic; at the bottom, along the cross-section, their mineralization increases from 13 to 48 g/l. The regularities stated above are evidence of the unity of the hydrodynamic system of the multipay field [1].
2. Materials and methods
Fractured-block tectonics of the West Siberian oil and gas province (OGP) determines formation of areas of destruction and development of fractured reservoirs in all producing depositions. In the course of vertical migration, hydrocarbons (HC) enter the cracks and capillary channels, commensurable with pores, having tectonic origin. As the distance from fractures increases, the oil saturation of reservoirs and the productivity ability of wells reduce [2-4]. The presence of exchange processes between the fractures and pores, prevalent development of vertical fracturing unite multi-bed fields into a unified hydro-dynamic system and enables the development according to permeability and porosity properties (PPP) of four types of reservoirs: fractured (F), porous fractured (PF), fractures-porous (FP), and porous (P). This is substantiated by differentiation of wells according to the flow rate into high-, medium-, and low-flow rate [1, 2]. Using the method of reservoir PPP assessment [1] by dependences of geological-production parameters on the skin-effect index and the skin-effect on the pressure drawdown [5, 6], it is possible to differentiate them by the indicator diagrams (figure 1).

Figure 1. Indicator diagram of well 1 of Samotlorskoye field. Points – a diameter of the connecting branch, mm; - selection from pores

During insignificant pressure drawdowns (to 2-3 MPa), drainage is carried out along the lateral, and exchange processes are not disrupted, which provides a long-term waterless operating period and working of nonhomogeneous in permeability reservoirs [6].

Insufficient consideration of reservoirs’ PPP, the opening-up of producing depositions with overbalance determine colmatation of fractures, and depending on the quality of drilling at the beginning of field development, the production level can correspond to the drainage of porous-fractured PF, fractured-porous FP, or even porous P reservoirs. The mechanism of purification of the fractured capacity affects explicitly the dynamics of development indicators (figure 2 a, b).

From 1969 to 1973 (coordinate origin – points 3, 3’), decolmatation of fractures took place, and the production level corresponded to porous P, fractured-porous FP, and porous-fractured PF reservoirs. This period is characterized by a low growth of water cut. Introduction of the waterflooding system (1970) and pumping large volumes of water, starting from 1975 (figure 2 a) excluded the oil inflow from pores to fractures (their permeability is 100-1000 times lower) and the reservoir was developed as a homogeneous-fractured F one, which in 1980 conditioned the achievement of the peak output. In succeeding years, in spite of the increased well stock and volumes of injection, the oil output was reducing, and in 1988, the working of homogeneous-fractured reservoir F was terminated. That period is characterized by a high growth of water cut up to 10-11% per year (figure 2, b). The wells were watered and taken out of operation.
Figure 2. Dynamics of mean (a) and total (b) yearly values of development of Samotlorskoye field. 1 - oil, 2 – withdrawal of associated water, 3 – water injection - all in conventional units; 4 – water cut (%); 5 – output well stock.
After the working of homogeneous-fractured reservoir F by the subsequent drilling-out of periclinal structures, the porous-fractured reservoirs PF, fractured-porous reservoirs FP (figure 2), which are the worst ones according to PPP, are worked; and with the water cut of about 90% (figure 2 b-t.A), their working is terminated. Since reservoirs F, PF, FP are characterized by negative values of skin effect, the fractured capacity contains basic recoverable resources (\(\Sigma Q_0 F\)).

Hence, the disruption of exchange processes leads to formation of hard-to-recover reserves on the areas with porous P reservoirs, on which the waterflooding system has no effect; therefore, the water cut has stabilized itself at a low level (figure 2 b).

Since destruction zones hydrodynamically unite all productive strata, during drainage of homogeneous-fractured reservoir F, there are interzonal communications from the fractured capacity, and cumulative production in separate wells reaches 3.5-3.6 mln. t (figure 3). According to the data of seismic survey, these wells are located in fractured junctures, which are formed by two systems of fracture zones, determined by disjunctive dislocations of early stages of structure development. Analysis shows that stock of such wells does not exceed 15-20%, and they account for 75-80% of cumulative production [7].

The revealed model of deposits is substantiated by the analysis of pattern efficiency. From the beginning of the development, the injected water enters only a high-permeability reservoir, and before 1975, the fractures experienced the inflow from pores, the production level was \(Q_{PF} \approx 0.5 Q_F\), which amounts to 2% of reserves [6, 8]. This regularity is reflected by figures 2a, 4a, 4b. Since frontal water drive took place, then after reaching the peak output and the working of reservoir F (1988), the output of associated water increased (figure 4 b). The recovery rate in this period reached 7% of recoverable reserves.

![Total oil output by wells (figures) of Samotlorskoye field.](image-url)
Figure 4. Assessment of waterflooding efficiency of Samotlorskoye field by dependences: a - $Q_o = f(Q_{out}^{inj})$, b - $Q_o = f(Q_{out})$, c - $Q_{out} = f(Q_{out}^{inj})$, d - $Q_t = f(Q_{out}^{inj})$, e - $Q_t/Q_{out}^{inj} = f(Q_{out}^{inj})$.

When draining such reservoir as PF, exchange processes are not disturbed and the associated water output is insignificant (figure 4 c). Deviation from the linear dependence in 1998-2015 (figure 4 e) is evidence of the waterflooding efficiency. At the same time, when working the fractured reservoirs in 1973-1995, $Q_t/Q_{out}^{inj}$ reduces to 0.6-0.9 (figure 4 e), which indicates cross-feeds or cross flows to the edge-water zone, and in this connection, the growth of unproductive water injections.
Conclusions
The above-mentioned information allowed making the following conclusions:

Multibed fields represent unified hydrodynamic systems. Hydrocarbon is contained in fractures and capillary channels (pores), between which exchange processes and development of four types of reservoir – fractured, porous-fractured, fractured-porous and porous – take place.

Injection of large volumes of water disturbs the exchange among fractures and pores and determines the separate working of reserves, which results in formation of hard-to-recover reserves on the areas with porous reservoirs.

The recovery yearly rate, not exceeding 2% of reserves, enables the simultaneous working of two media, reduces the growth of water cut, unproductive water injections, volumes of hard-to-recover reserves, and provides reaching a higher productive rate.

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