Problems of shale oil hydrocarbons, ultra-viscous oil reservoirs and natural bitumen deposits development in Tatarstan

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Abstract. The area of the Volga-Ural oil and gas basin belongs to the “old” oil and gas bearing regions. The most part of easily recoverable reserves of large and unique oil fields already have been developed within the area. Therefore, super-viscous oil reservoirs, natural bitumen deposits and shale hydrocarbons seized the attention of local petroleum geologists. Tatarstan is a classic example in that sense. The Republic of Tatarstan is a leader in the development of heavy oil resources, a leader in the degree of knowledge of natural bitumen accumulations, as well as a leader in technological readiness for their development. In the depths of Tatarstan, there are more than 450 fields of ultra-viscous oil and natural bitumen with reserves ranging from 2 to 7 billion tons of this type of hydrocarbons. However, their industrial development due to low profitability is slow. To solve the problem, it is necessary to search for and commercialize economically viable technologies for the production, transportation and processing of hydrocarbons, which take into account its features and do not require increased energy and other material costs. Therefore, the search for the right unconventional hydrocarbons production concept is an urgent problem of our time.

1. Introduction

Using the fundamental knowledge and accumulated Russian and international experience in the study and development of super-viscous oil reservoirs, natural bitumens and shale hydrocarbons, one can approach the effective industrial development of heavy hydrocarbons.

Most of the foreign programs on the use of natural bitumens and super-viscous oils, ranging in value from a few million to several billion dollars, have been compiled taking into account all the features of the mineral resource, the size of deposits, extraction conditions, etc. Despite the expected significant growth in extraction of natural bitumen (from 78 million tons in 2010 to 240 million tons in 2035 mainly due to Canada) and biofuels from 75 million tons in 2010 to 145 million tons in 2035 (mainly in the USA and Brazil), the most favorable conditions for increasing the production of unconventional hydrocarbons are associated with shale oil reservoir development. United States are leading in this area. There are more than 20 large shale oil basins in the US, the largest of which are located in the west of the country in the states of Utah, Wyoming and Colorado. Theoretically, among the countries which have shale gas and shale oil, Russia can take a leading position because it has a developed infrastructure, great oil and gas potential, and can quickly master the technology of multi-stage hydraulic fracturing in horizontal wells achieving its high profitability in areas of high-carbon formations (Bazhenites and Domanikites), the potential sources of shale oil and gas. In addition to
shale hydrocarbons, huge reserves of heavy oils and natural bitumen are concentrated in Russia. The Republic of Tatarstan is a leader in the development of this type of hydrocarbons. Downhole and mine development methods are the main methods of natural bitumen production. Using the downhole methods, natural bitumens are produced after a preliminary increase in their mobility in the reservoir by heating. Heating can be carried out by steam injection, steam gas injection, in-situ combustion, etc. Mining Methods include Mine Development Method and Open Pit Development Method. In this methods, the rock is delivered to the surface, and then the natural bitumens and high-viscosity oils contained in the rock are extracted with solvents, hot water, steam with surfactant additives, alkalis, etc. The selection of a system for influencing natural bitumens, super-viscous oils and shale hydrocarbons should be based on global criteria for the applicability of enhanced oil recovery methods.

At present, Canada took the leading position in terms of oil production from bituminous sandstones. Over 150 million tons of synthetic oil per year is produced from the Athabasca sandstones of Alberta province.

Bituminous sandstones of Alberta are being developed [3] using surface mining methods by such companies as Syncrude, Suncor, Shell, etc., as well as using downhole methods (“in situ production”) by such companies as Petro-Canada, Nexen-Opti, Imperial Oil, etc. The level of oil recovery for Mining Development methods averages 90% and reaches 70% for the downhole methods.

Some new promising methods and technologies are being tested at the pilot stage. In particular, the following technologies should be noted: Solvent Aided Process (SAP), the combination of in-situ combustion (vertical well) and oil production from a horizontal well (THAI - Toe to Heel Air Injection), Electro-Thermal Dynamic Stripping Process (ET-DSP), Sonics-Pressure Pulsing and technology with injection of nitrogen, nitrogen and carbon dioxide or carbon dioxide only.

2. Methodology
There are a number of different and considering successful ultra-viscous oil and natural bitumen production technologies. Various development approaches have been tested in the process of pilot works at the Mordovo-Karmalsky and Ashalchinsky fields of viscous and highly viscous oils (Tatarstan) in the sandstones of the Ufimsky Stage [2, 3]. The development technologies using horizontal wells and the technologies combining impact on the formation by use of thermowave emitter and a steam-gas generator have proved themselves most effective. Significant practical developments have been made in the study and exploration of the bituminous sandstones of the Ufimian Stage. Positive results of hydrocarbons extraction were achieved during a number of pilot works. In September 2018, ultra-viscous oil production amounted to 165,210 tons, and reached 1,432,719 tons from the beginning of the year (for 9 months) resulting in more than 5 million tons produced over the entire period of ultra-viscous oil reservoirs development. Most part of ultra-viscous oil was extracted by horizontal wells, the flow rates of which are 8-10 times higher than flow rates of vertical ones.

The development of shale hydrocarbons, super-viscous oil and natural bitumen in Tatarstan is complicated not only by the lack of currently tested cost-effective technologies for their production,
refining, transportation, but also by the unresolved individual issues of subsoil use and scientific design of unconventional hydrocarbon development schemes which would be based [4] on the study of the reservoirs geological structure, knowledge of the basic laws in changing developing site selection criteria in accordance with specific lithofacial zones [1, 5, 6, 7]. Thus, the new scientific approach presented in the article for solving the problem of unconventional sources of hydrocarbons development is based on a system analysis: from the detailed geological structure of strata containing unconventional hydrocarbons, studying the formation conditions and patterns of hydrocarbon accumulations to the preparation of oilfields for development.

3. Results and Discussions
The study of the reservoirs’ geological structure saturated by unconventional hydrocarbons allows [4] to systematize groups of oilfields with a common lithological and petrophysical composition of reservoirs, depth, shape and size of hydrocarbon traps, screening capacity of caprocks, physical and chemical properties of saturating fluids, etc. The identified features will contribute to the development of geological and geochemical criteria for ranking and determining rational production methods (based on the world experience of heavy oil reservoirs and natural bitumen deposits development as well as on criteria for the application of foreign and Russian technologies) and the sequence of launching oilfields into operation [1].

The Domanikites containing shale hydrocarbons have the following features: 1) anomalous material composition 2) limited stratigraphic prevalence, 3) confinement to the eastern part of the Russian Plate.

Reason of the anomalous material composition is the presence in the rocks of the following main rock-forming components: quartz (chalcedony), calcite and organic matter. The content of the latter can vary widely from the first percent to 20-30%, or even more in rare cases.

The limited prevalence of these rocks is due to their limited stratigraphic position. Such rocks are developed only in the sediments of the Semiluksky (Domanik) horizon of the Fransian stage of the Upper Devonian. Their thickness is usually the first tens of meters. Such sediments are no longer found in the section of the Volga-Ural region sedimentary cover, the thickness of which is about two thousand meters. However, they are very widespread in the shape of a meridional strip along the western slope of the Urals and cover large areas. The Semiluksky (Domanik) horizon deposits look like a belt that stretches along the Urals from north to south from the Pechora Sea to the Caspian syneclise through Bashkortostan and Tatarstan.

Based on the available data, it has been established that such formations form a cyclical pattern of different ranks, which is associated with hydrothermal activity, eustatic fluctuations of sea level and climatic changes. According to [8], an important role in the domanikites formation belongs to hydrothermal fluid systems or systems related to them.

Our own studies [10] showed that the studied sections were composed of three following lithotypes: carbonate rocks, carbonate-siliceous rocks with a high content of organic matter and carbonate breccias comprised of carbonate fragments cemented by a carbonate-siliceous material enriched in organic matter.
It should be noted that there is another feature of the core material studied: the presence of feldspars and mica in the carbonate-siliceous lithotype [11]. The presence of these minerals in the rocks cannot be explained by the terrigenous introduction of the material, since Domanikites are developed among carbonate (not terrigenous) rocks (limestones). Therefore, carbonate breccias, given the irregular position of such rocks in the studied sections and the impossibility of their correlation, suggest their lenticular shape.

Another important fact, in our opinion, that allows a more rigorous discussion of the domanikites sedimentogenesis conditions is the established relationship of organic matter with the siliceous component of sediments. According to the data based on the study of the samples mineral composition and their organic matter content, there was identified the dependence indicating that the organic matter content increases with the increase in proportion of quartz in the rocks.

Endogenous fluids that supplied silica acted as a source of substance for the formation of quartz (chalcedony) of carbonate-siliceous rocks. Their periodic activity ensured the cyclicity in sedimentation.

As part of endogenous fluids, there were also some biophilic elements, which ensured high bioproductivity and accumulation of organic matter having a sapropelian genesis.

The following additional facts that do not contradict the previously established concept, and which require an explanation appeared in the process of studying core samples:

- the relationship of silica accumulation with accumulation of organic matter;
- the presence in the sediments of not only limestone and carbonate-siliceous rocks, but also carbonate breccia;
- connection of biophilic chemical elements with carbonate-siliceous rocks enriched with organic matter;
- Domanikites development among carbonate rocks (limestones).

The relationship of silica accumulation and accumulation of organic matter can be completely explained by the fact that the formation of sediments took place under the conditions of the so-called fluid lithogenesis, when endogenous fluids served as one of the material suppliers for the formation of sediments. This led to the formation of the siliceous component of the domanikites and also the feldspathic and mica components of the domanikites, which are only found in carbonate-siliceous layers. At the same time, the fluids introduced trace elements with themselves, which, being biophilic, contributed to the development of biota and the formation of sapropelium substance.

The material of hydrothermal, and, perhaps, volcanogenic origin could provoke a rapid increase in the development of biota. Thus, released CO₂, silica, methane and trace elements could lead to the flowering of certain organisms and the oppression of others. Thus, the abundance of silica may be associated with the appearance of masses of silicon-forming organisms, while methane and other components could cause a rapid increase in the development of biota.
Such an interpretation of the sedimentation process does not indicate the formation of domanikites in the conditions of a long-existing reducing environment, since the preservation of organic matter may be due to its high content in the sediment. Complete oxidation of organic matter becomes impossible under conditions of a very high rate of its accumulation. However, such a statement can be contested and requires additional confirmation.

Carbonate breccias formed due to turbiditic flows (underwater-landslide flows), which according to our opinion have arisen due to the changes in sea level within the transgressive marine basin. The latter should probably be considered as the most promising objects for the possible development of domanikites. However, the assumption made needs thorough justification.

4. Conclusions
It was identified by many researchers that Domanic deposits were formed during an extensive marine transgression from the Paleoural, the maximum of which was observed in the Semiluksky time. Therefore, taking into account the ubiquitous and irregular presence in the section of the Domanik carbonate breccia deposits, it is possible to propose the most likely way of their formation. According to our understanding, under the conditions of the marine basin transgression, a certain “barrier” is formed on the seabed separating the carbonate accumulation area from the accumulation area of carbonate and carbonate-siliceous material (domanikites itself) with periodic inflow of endogenous fluids to the bottom. At the same time, endogenous fluids, in addition to the main component of silica, also supplied biophilic chemical elements that led to the mass formation of biota. The “barrier” formed during the transgression serves as a factor in the formation of turbidites or similar gravitational flows, and, as a result, the introduction of detrital carbonate material into the forming domanikites. This method of carbonate breccias formation is in many ways analogous to one of the hypotheses of the anomalous Bazhenov sections formation by underwater-landslide penetration into it of terrigenous aleurite-sand size material. Similar rocks in some publications are attributed to oil-bearing ones.

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