The first data on the porous space structure of the Domanik
shales as a potential object for EOR applying

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Abstract. The resources of shale oil, contained in the organic matter of the wood deposits, can be considered as a source of profitable production of hydrocarbons, when modern EOR technologies are used. As a result of the primary studies of the pore space structure, it is revealed that two types of porous space are prevailing in the studied samples of the Domanik oil shales. The most prevailing is intrakerogen porosity with pore volumes of $5 \times 10^{-8}$ $1 \times 10^{-6}$ mm$^3$. The volumetric reconstruction of the structure of this pore space shows that the voids are confined directly to micro lenses of organic matter. The second type of the found void is represented by leaching cracks. It is characteristic of more carbonate varieties of the Dominik oil shale with spotted structure. It is the oil shale intervals with such cracks that are of greatest interest to the EOR, since they consist of a large area with smaller pores and through which pressurization and spread of various agents are possible to occur in order to increase the oil recovery.

Keywords: Domanik, porous space, shale, source rock, shale oil, unconventional resources, microCT, X-ray computed tomography, EOR.

1. Introduction

Under the conditions of the traditional energy resources depletion, shale and high-viscosity bituminous oils are becoming increasingly important in the world economy. The resources of oil shale - "immature" oil contained in the organic matter of the wood deposits can be considered as a source of profitable production of hydrocarbons, when modern technologies are used. Synthetic oil from the oil shale contains more organic matter than, for example, tar sands of Canada, developed on an industrial scale [1].

It was believed that the Domanik deposits were only a proven high-yielding oil-bearing stratum that generated hydrocarbons for most of the deposits in the overlying carbonate structures of the Volga-Ural and Timan-Pechora basins. At the same time, the Domanik horizon itself contains a considerable amount of hydrocarbons, which have not yet emigrated.
This gives the right to consider the Dominik stratum as a single unstructured hydrocarbon deposit, from which part of the hydrocarbons has left and migrated into structural traps, and most of them have remained and they are the underexplored hydrocarbon resources [2].

Domanik deposits of the Volga-Ural Basin are a high-carbon thin-bedded formation that is capable of both producing hydrocarbons with its own oil and gas reservoirs and concentrating them in separate strata and zones that serve as a reservoir. About 10 oil fields are discovered here, the extraction of which is not carried out. Its inflows are from 15 to 120 tons per day. The technically recoverable oil resources of Domanik are 898 million tons [2, 3].

In the last decades, the applications of horizontal well technology have been widely facilitated by the surging of unconventional reservoirs. At a low drawdown, a horizontal well can have a larger productivity in comparison with vertical wells. The major advantage of horizontal well technology is to enhance the contact area with the formation. Hydraulic fracturing has received the great recognition for one of the most effective techniques for improving the productivity of unconventional reservoirs. Combination of horizontal well with multi-stage hydraulic fracturing and development of different EOR methods, such as cyclic steam simulations (CSS) and cyclic gas stimulation (CGS) techniques can promote the booming of development of shale oil reservoirs [4].

Shale oil and shale gas are present in organic rich rocks, which may act both as the source and the cap rock and can be mixed with clay minerals. Organic materials preserved in rocks have come from the decay of plants and animals. The sediments can retain much of their original organic material in anoxic environment where there is less consumers to consume organic matter. As more material accumulates and underlying ooze becomes compacted, the sediments are buried deeper and subjected to heat and pressure. The organic material slowly and partially is made and transformed into kerogen, depending on the time and temperature at which these materials are made. The transformation of living organisms through diagenesis into kerogen, kerogen will break down to form hydrocarbons through a chemical process called catagenesis [4].

Shales are fine-grained rocks, which are formed from the compaction of silt and clay sized particles. Shales are differentiated from other claystones and mudstones in that they are laminated, finely layered and fissile that mean, they can be broken along their laminations [5]. Shales can have complex mixtures of minerals, and the relative connections of the constituents that have the potential to make or break a potential resource play [4]. This is the reason why research of porous structure of shales is important for unconventional resources recovery of the Domanik formation.

2. Samples and methodology

Two core samples from the Domanik formation of the Republic of Tatarstan were researched. First one was gray carbonate shale, the second – a typical black finely layered and fissile shale. For this study X-ray computed microtomography (microCT) was used. For microCT cylinder samples with 2,5 mm in diameter and 2,5 mm in height were made and 3 ηm
resolution of tomography was reached. MicroCT was made by micro and nanofocus X-ray control system for computed tomography General Electric V|TOME|X S 240. Virtual models of the porous structure and measurements performed by Volume Graphics 2.1 and Avizo Fire 8.0 software.

3. Results and Discussions

The obtained results give the first information about the structure of the rock and the porous space of the Domanik oil shale. On the density X-ray orthogonal sections of the sample 1, a spotted texture is distinguished, the dark parts of which correspond to the areas, which are the most enriched in kerogen (Figure 1). Light gray parts are confined to areas with a high content of minerals - in this case mainly calcite. The brightest white points are inclusions of pyrite formed by bacterial sulfate reduction under reducing conditions. In the researched sample, a diagonal crack formed due to leaching is clearly observed. It is noted that it goes round the light-gray mineralized carbonate areas.

Figure 1. MicroCT orthogonal slices of the sample 1. In the picture the spotted texture is observed, where dark zones are interopereated as kerogen rich, light gray zones – carbonate rich, white – pyrite crystals. On the top right part of the picture a leaching crack is represented.

The sample 2 is distinct in a thin-bedded texture (Fig. 2). The dark zones are enriched with kerogen, light grey – quartz. As distinct from the first sample, the amount of pyrite and pores is significantly low.
Figure 2. MicroCT orthogonal slices of the sample 2. Thin bedded texture is observed: dark zones correspond to kerogen rich areas, light gray zones – quartz rich, white – for pyrite crystals.

The information on porosity and pore size distribution in the studied samples is given in the table and in the Fig. 3. The porosity value coefficient for the shales is about 1%. In both samples, an equal pore distribution is observed in the volume range from $5 \times 10^{-8}$ to $1 \times 10^{-6}$ mm$^3$. We associate such ranges of pore volumes with intra kerogenous porosity. This is indirectly confirmed by the correspondence of the kerogen lenses distribution to the areas of the maximum pore accumulation of the given dimension in the sample 2 (Fig.4) that leads to the single direction of the stratification and pore accumulation areas.

Table 1. Statistic data on porous space of the samples.

| No. | Parameter                              | Sample 1   | Sample 2   |
|-----|----------------------------------------|------------|------------|
| 1   | Min                                    | 5,22E-08   | 5,22E-08   |
| 2   | Max                                    | 0,0230     | 3,02E-05   |
| 3   | Mean                                   | 1,61E-07   | 1,02E-07   |
| 4   | Sum                                    | 0,2553     | 0,2152     |
| 5   | The volume of the sample, mm$^3$        | 21,0158    | 32,5160    |
| 6   | Porosity, %                            | 1,2147     | 0,6618     |
| 7   | Pores number                           | 1586798    | 2105755    |
Figure 3. Pores distribution of different volumes in the rate of total volume for the samples.

For the sample 1, in the range $2.7 \times 10^{-3}$-$2.4 \times 10^{-2}$ (see Figure 3), a large volume is observed associated with the leaching crack (Fig. 5). In the authors’ opinion, the oil shale intervals with such cracks are of the greatest interest to EOR, since they include a larger area with smaller pores, connecting them to each other. In addition, the pressurization, as well as the penetration and spread of various agents in the formation are occurring through them.

Figure 4. Correspondence of dark kerogen-saturated areas to the areas of small sizes pores in the sample 2. For this reason, the image shows an equal inclined direction of the thin stratification and pore distribution.
4. Conclusions

As a result of the conducted studies, it is revealed that two types of porous space are common for the studied samples of the Domanik oil shales. The most common is the intra kerogen porosity with the pore volumes of $5 \times 10^{-8} - 1 \times 10^{-6} \text{ mm}^3$. The volumetric reconstruction of the structure of this pore space shows that the voids are confined directly to micro lenses of organic matter. The second type of the found void is represented by leaching cracks. It is characteristic for more carbonate varieties of the Dominik oil shale with a spotted structure. The oil shale intervals with such cracks are of greatest interest to the EOR, since they consist of a large area with smaller pores and through which pressurization and spread of various agents are possible to occur in order to increase the oil recovery.

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