Abstract

Carbonate oil reservoirs begin to play an ever increasing role in the development of oil production in Russia, as new oil-bearing regions and deeper lying formations become involved in geological prospecting works. These reservoirs, confined, as a rule, to massive formations, are characterized by appreciable heterogeneity of capacity and flow reservoir properties, resulting in high variability of well productivity. Carbonate rock heterogeneity is caused, primarily, by variations in the structure of rock void space. In spite of the fact that more than 15% of oil in Russia is produced from carbonate reservoirs and this part is constantly increasing, most of such reservoirs remain uninvolved in commercial production due to their complicated geological structure, uncertainty in oil reserves in them, rapid decrease in well productivity and some other reasons.

At the same time, a great variety of carbonate objects, considerable experience in oil field development and application of various IOR/EOR technologies ensure a more substantiated approach to projecting and development of such oil fields. In order to estimate prospects of oil production from carbonate reservoirs, it is necessary to investigate the following:

1. Structure of Oil Reserves in Carbonate Reservoirs

The type of carbonate reservoirs is determined by their capacity and flow properties. The following types of carbonate reservoirs were singled out by the authors from a variety of carbonate reservoir types - porous, combination, fractured and reef (Fig. 1).

In Russia, the greater part of explored oil in carbonate reservoirs is concentrated
in porous ones. This type of carbonate reservoirs is found in Tatarstan, Bashkortostan, Komi and Udmurtia republics, in the Arkhangelsk, Samara, Orenburg and Perm' regions, where carbonate reservoirs differ only slightly from terrigenous formations under good reservoir conditions. They are characterized by high porosity and permeability, high rate of oil withdrawal and high oil recovery values.

Reservoirs with a complicated structure, determined as fractured-porous-cavernous according to the structure of their void space, are referred to as combination type. Many of them are attributed to bioheren forms. This type of carbonate reservoirs are found in the Orenburg Region, East Siberia and Yakutia.

Fractured reservoirs are often found in the Upper Cretaceous deposits in the Chechnya Republic and Stavropol' Region. These types are massive and extremely productive.

Reservoirs, confined to reef massifs, are characterized by a great variety of lithological and petrophysical characteristics of rocks, appreciable variability in their reservoir properties and resulting complicated pattern of porous and permeable zones occurrence within the formation. Carbonate reservoirs of this type are widely spread in the Bashkortostan Republic, as well as in the Arkhangelsk, Volgograd and Saratov regions.

2. Current State-of-the-Art of Reservoir Development

Analysis of the current state-of-the-art of oil production from carbonate reservoirs demonstrates their lower efficiency, as compared to terrigenous objects. Oil recovery in carbonate reservoirs, as well as rates of oil withdrawal from them are lower than for objects in terrigenous ones. This is explained mainly, by the fact that, by the present moment, no large oil reserves confined to purely carbonate reservoirs have been discovered in Russia. At the same time, in the productive section of most of the oil fields in the Volga-Ural Oil-Gas Bearing Province, there are carbonate reservoirs containing much oil. However, the possibility of achieving higher withdrawal rates and higher oil recovery values in terrigenous reservoirs put off the necessity in complex development of oil reserves in carbonate reservoirs. The use of traditional methods of carbonate reservoirs development often did not ensure oil production increase and oil recovery enhancement. Figure 2 presents the distribution of oil reserves in carbonate reservoirs, involved in production, classified according to the degree of their recovery. It is clear from this Figure that about 70% of oil reserves are actually not involved in production. Oil reserves in reef and fractured reservoirs are recovered to the greatest extent. The degree of their recovery exceeds 90 and 80%, respectively. The recovery of oil reserves in porous reservoirs makes about 40%. Objects in reservoirs of a combination type are least recovered. The degree of their recovery is about 25%. Oil withdrawal rates at different production stages were analyzed for numerous carbonate objects, which have been in production for a long time, depending on their geological properties, reservoir type and applied development system. Figure 3 presents dependences of averaged oil withdrawal rates on the degree of recovery of recoverable reserves. This analysis has shown that reservoirs of a combination type are characterized by highest withdrawal rates at the second production stage. However, the short duration of this stage, followed by a sharp reduction in
oil withdrawal rates, entails the decrease in the total degree of oil reserves recovery.

Oil reserves, confined to the fractured type of reservoirs (Upper Cretaceous deposits in Chechnya) are characterized by a comparable uniformity in the recovery of recoverable oil reserves and high oil withdrawal rates (over 10%) at the second production stage. This is explained by large thickness of oil-saturated layers, resulting in the subsequent transfer of perforation intervals in producing wells during the rise of water-oil contact under the conditions of effective hydrostatic upthrust of the underlying aquifer.

Oil reserves in Permian deposits of Bashkortostan, confined to reef massifs, are characterized by high oil withdrawal rates at the second production stage (about 10% per year), short duration of the stage (some 2 years), and, respectively, by a low degree of recovery of recoverable oil reserves. This is related to the fact that appreciable heterogeneity of objects did not allow for the application of waterflooding, and the reservoirs were developed at depletion drive.

Porous carbonate reservoirs in the Ural-Volga Region, confined to Bashkirian and Turnean Stage deposits and deposits of the Vernean Horizon, are characterized by medium withdrawal rates at the second production stage (6 - 8% per year) and a smoother decrease in oil production at the third stage. As was mentioned above, this is explained by the fact that geological characteristics of these reservoirs are similar to those of terrigenous ones. Another reason for this is a wide range of reservoir stimulation techniques applied.

Low efficiency of oil production from carbonate reservoirs can be caused by incompatibility of the applied oil production methods with geological conditions of individual reservoirs, characterized by fractured and cavernous structure, a variety of lithological types of rocks, increased geological heterogeneity with regards to numerous parameters and complicated structure of the pore space. Under such non-standard conditions, the projecting and development of carbonate reservoirs is often implemented without sufficient differentiation. Sometimes, the above-mentioned peculiarities of their structure are, actually, neglected.

The account of carbonate reservoirs peculiarities necessitates using geological-mathematical modelling, allowing for the description of the geometric configuration of a certain reservoir and spatial variability in its parameters over its whole volume. Appreciable heterogeneity of carbonate reservoirs, caused by the effect of secondary rock-forming processes (leaching, fracturing, dolomitization, etc.) on the capacity and flow properties of rocks requires the use of deterministic-probabilistic approach to the simulation of such reservoirs. This modelling technique is a good basis for three-dimensional hydrodynamic calculations with the use of different flow models (piston displacement, account of mass exchange between the matrix and fractures, porous filtration) for various types of reservoirs within one and the same formation. The use of differential geological models in combination with up-to-date mathematical models allows for a more accurate evaluation of prospects of oil production from carbonate reservoirs. According to preliminary estimates, it can decrease 1.5 - 2 times the cost of drilling and surface facilities organization at an oil field. Besides, this will ensure a detailed analysis of oil production, aimed at selecting the optimum methods of its
intensification and oil recovery enhancement.

3. Generalization of the Applied IOR/EOR Techniques

Various IOR/EOR techniques are applied mainly to stimulate the matrix of carbonate reservoirs, from which oil is not, actually, produced. Basing on the results of statistical procession of geological characteristics and operation data, available for more than 200 carbonate reservoirs of different types, we obtained dependences of oil recovery on the most relevant parameters. For reservoirs with the porosity exceeding 10%, the dependence between oil recovery and porosity is of a traditional character. On the contrary, for mixed carbonate reservoirs with the porosity not exceeding 10%, an inverse dependence was obtained, i.e. the higher the porosity, the lower the oil recovery. This inverse dependence testifies to the non-involvement of oil reserves of the matrix into traditional production process, and thus, the higher the porosity of such reserves (within the above-mentioned limits), the larger the unrecovered oil reserves.

In order to estimate prospects of the application of different IOR/EOR techniques for carbonate reservoirs, a bank of new technologies, based on the geological properties of reservoirs, current reserves structure and state-of-the-art of objects development, (Fig. 4), was created at the All-Russian Oil and Gas Scientific and Research Institute (VNIINeft). This bank, which includes technologies that have passed the stage of pilot and commercial testing, will ensure a reliable estimation of prospects of the application of individual IOR/EOR techniques, required capital investments and economic efficiency of new technologies. About 50% of these technologies are related to objects with heavy oils and with the involvement of new oil reservoirs, not enveloped by primary stimulation (40%), in production.

4. Prospects of Carbonate Reservoirs Development in Russia

The main prospects of carbonate reservoir development in Russia are connected with two main directions:
(1) involvement of new oil fields in production. The main areas in question are the Arkhangelsk Region, East Siberia and Yakutia, as well as deep-lying objects of the Saratov and Volgograd regions. Some 50% of oil reservoirs in these regions are confined to carbonate reservoirs. Their recovery is less than 10%. These reservoirs are mainly of combination and reef types, characterized by high initial productivity. The use of geological-mathematical and hydrodynamic modelling, combined with our practical experience in developing such reservoirs, will ensure the elaboration of an effective development strategy for such objects. At the same time, while elaborating such strategy, one should take into account the fact that in East Siberia and Yakutia the involvement of new oil fields in production is hampered by underdeveloped infrastructure, severe natural and climatic conditions, complicated geological conditions, and the absence of oil consumers in the region;
(2) development and practical application of new IOR/EOR technologies, as well as a wide range of traditional ones (horizontal drilling, gas and water-gas stimulation, polymer waterflooding, etc.) will ensure the increase in oil withdrawal rates, oil recovery values by 5 to 7% for oil fields in production in the Central part of Russia.
Fig. 1 Distribution of balance oil reserves in carbonate reservoirs in accordance with reservoir types: 1-porous, 2-combination, 3-fractured, 4-reef
Fig. 2. Distribution of oil reserves involved in production in carbonate reservoirs according to the degree of recovery.
Fig. 3. Dependence of rates of oil withdrawal from different types of reservoirs on the degree of recovery of recoverable oil reserves.
1-in waterflooded reservoirs, 2-on areas, not involved in primary stimulation, 3-in reservoirs with heavy oil, 4-in water-oil zones of the reservoir, 5-in sub-gas zones of oil fields with a gas cap.

Fig. 4. IOP/EOR technologies, applied to carbonate reservoirs, classified according to geological areas of their application.