The wide and effective use of pattern flooding ensured very high oil production rates from the very beginning of oil development in the former USSR. As a result, the USSR reached a record-high oil production level of about 625 MM tonnes per year. Further, progressive steps included the wide use of the methods of enhancing oil recovery (EOR) and various bottom-hole treatment techniques.

However, despite these advances, the design oil recovery — the key parameter reflecting the rational use of subsoil resources — is still on a long-term decline in the country.

In recent years, the average design oil recovery that was maintained during the last 50 years has decreased 1.5 times to become 1.2 times lower than in the USA where oil recovery has been increasing for many years though the structure of the US reserves is not better than in Russia (Fig. 1). In Russia, 65% of reserves remain in place. Due to this negative trend, the decrease in potential recoverable reserves has already amounted to 15 billion tonnes, i.e. nearly as much as has been produced throughout the history of the Russian petroleum industry (Fig. 2).

Since the first calculation of oil reserves for the Romashkino field in 1954, oil recovery in Tatarstan has decreased 1.5 times. This fact is mainly explained by dramatically deteriorated development conditions due to the following factors:

- Discovery of numerous fields with a great variety of difficult reserves in unconventional reservoirs, anomalous oil types and specific occurrence of pay beds;
- Depletion of oil reserves in the country’s largest fields, which accounts for the sharp decrease in oil production rates, high water cut, deteriorated production and economic performance, and in some cases makes the development of particular areas and deposits unprofitable.

All these factors have their effect but are not the key cause of the decreased oil recovery. However, oil recovery continuously increases in the USA and continuously decreases in the Russian Federation.

The loss of oil recovery in the Russian Federation takes place mainly due to inadequate consideration, in the course of the reservoir engineering, for the geological structure of the development target and for technogenic changes in the field during its long-term exploitation and due to the still existing old Soviet system of oil reserve classification by the State Reserves Committee.

Technogenic changes are caused by the flooding faults that have been detected during the long-term development of Romashkino, the first oil field in Tatarstan to test contour flooding (Muslimov, 2003). These faults can be listed as follows:

- In the development process, the separate, heterogeneous zones are not fully flooded and, as a result, a considerable amount of difficult oil remains undeveloped and productive beds are developed at different rates, which leads to premature flooding of high-permeability reservoirs;
- Remaining oil in these flooded beds is sealed by injected water that complicates their development, and asphalt-resin paraffin sediments are deposited at the bottomhole and in adjacent zones;
- Degradation of residual oil leads to the formation of oxidised, sulphurised, low-mobility and immobile, biodegraded oil in the reservoir;
- Production of remaining, recoverable reserves from undeveloped or underdeveloped, low-permeability reservoirs that are adjacent to the flooded ones becomes problematic due to the paraffin deposition caused by the formation temperature drop (reservoir overcooling) in the course of cold water injection and oil degradation (increased viscosity, weight and sulphur content);
- In the course of the long-term development, reservoir permeability decreases for the above reasons and due to the ongoing deformations in the reservoir caused by the pressure drop (varying openness of fractures, rock deformation and movements of rock matrix clay) (Muslimov, 2005; Sakhipgareev & Slavin, 1991).

This results in technogenic changes in geological and physical oil field properties (permeability, dynamic stress conditions of rocks, oil composition and hydrodynamic, hydrogeological and temperature regimes). Regrettably, these factors are not taken into account in further designing, and a wider flooding coverage is achieved by the large number of geological and technical actions including the drilling of additional wells.

However, reservoir engineers still do not take into consideration the above oil field features, which reduce the previously designed oil recovery. In some cases, design documents give a rationale for reduced oil recovery in comparison with the previously approved, but not due to the technogenic alteration of oil field properties, and the other ones are based on the previously approved oil recovery but this is supposed to be achieved by numerous, additional, unforeseen actions, such as down-spacing, more intensive flooding and a greater number of EOR and well stimulation methods.

Under these circumstances, engineers should apply technologies that are more advanced with regard for technogenic changes in deposits caused by their long-term exploitation, and EOR developers should create dedicated technologies to handle technogenic changes in depleted deposits.

In numerous oil fields of Tatarstan, actual oil recovery factors differed from the officially approved ones, although to a minor degree. In low-yield fields with difficult oil, oil recovery cannot be calculated at the initial stage. In such cases, a rationale can only be generated for the development system through pilot production operations to be performed to try out appropriate technologies. This will allow the selection of technologies and the setting of commissioning time. In the absence of efficient technologies to be used for the cost effective development of low-yield deposits, production operation should be postponed.
Despite extensive, more than 60 years experience in the development of Tatarstan’s oil fields, some most geologically complex deposits still cannot be efficiently developed in the Republic. These are primarily the deposits in structurally complex, highly heterogeneous, carbonate formations, which in many cases contain high-viscosity, heavy oil.

The use of the existing system of calculation and approval of oil recovery factors leads to a paradoxical situation: the development equipment and technologies keep evolving while oil recovery is constantly decreasing. In contrast, the US system suggests the initial approval of actually achievable oil recovery. As the development equipment and technologies evolve, it is revised in the course of designing.

Amendment of the oil recovery approval procedure should be followed by the creation of techniques and instructions for the routine, annual accounting of recoverable reserves increments due to the introduction of new EOR methods. The new market environment has made this goal more difficult to achieve for oil companies. At the initial stage, it encouraged research teams to boost their efforts in the implementation of new EOR methods. Before this trend started, they developed new technologies to reserve some of them for further use, but the market-related problems forced them to apply these technologies in the production process.

New EOR methods were in some cases introduced under contracts between the subsoil user and the patent holder. New technologies were implemented through the creation of joint ventures with foreign participation (Tatolpetro, Tatoilgaz and Tatex), and the newly created Russian enterprises operating with EOR methods on a production sharing basis.

In the initial period of market reforms, the Government of the Republic created favourable conditions for the development of new EOR methods and for their large-scale implementation. The development of new EOR methods and pilot production were financed from the funds for the replenishment of mineral resources, and additional oil was produced using various tax incentives.

However, in the market environment and in the absence of the state control the production of the remaining recoverable reserves was also considered to be due to the use of EOR methods. Moreover, it is impossible today to estimate the annual production of oil in Russia by tertiary recovery methods. The production operations conducted by Zarubezhneft OJSC in 2006 using EOR methods can serve as an example (Fig. 3). According to their estimates, these figures are underrated while other oil companies overrated them.

In 2006, EOR methods allowed the production of 5877 thous. tonnes of oil in Tatarstan including about 1200 thous. tonnes by well stimulation. Oil output by EOR methods until the year 2020 is given in Fig. 4. A generally applicable method of calculating recoverable reserves increments due to EOR methods should be developed. This is particularly important as the accretion of recoverable reserves due to the use of EOR methods is the second largest component of the annual reserves increment alongside with the conventional exploration techniques. The role of EOR methods in the replenishment of mineral resources grows with time (Fig. 5).

Enhancing oil recovery from mature deposits largely means the extraction of residual oil. The total amount of oil in pores is determined by conventional laboratory methods. Mobile oil (displaced by normal water), low-mobility oil (displaced by treated water) and residual immobile oil (that cannot be displaced by water) can be detected by NMR spectroscopy using oil displacement models. Notably, the amount of low-mobility oil depends on the tertiary EOR methods applied.
Nuclear magnetic logging (NML) can presently determine the amount of mobile oil under field conditions. The remaining oil can be considered immobile. Laboratory data suggest that some portion of immobile oil can be extracted by tertiary EOR methods, but even these methods cannot recover the remaining portion. This approach allows the following classification of oil reserves: mobile (extracted by hydrodynamic methods), low-mobility (extracted by integrated hydrodynamic and tertiary EOR methods) and immobile reserves that cannot presently be extracted.

The mature field is a technogenically changed one. As a result, some portion of recoverable design reserves is lost in place due to imperfect flooding techniques and inadequate implementation of design solutions. At the same time, EOR methods allow the production of some slightly changed oil of the design and, partially, unrecoverable reserves to compensate for and even exceed the recoverable reserves that were lost in place (Fig. 6).

Another issue to deal with is the development of bitumen. Bitumens can be considered unconventional sources of hydrocarbons. Permian bitumens of Tatarstan are oxidised, high-viscosity, liquid, semi-liquid and hard oils with a viscosity of 600 to 440 thou. mPas, a sulphur content of as much as 3.7 – 7%, an oil content of 5.8 – 88%, a resin content of 8.7 – 57% and an asphalt content of 3.3 – 61%.

However, bitumen is much more difficult to develop than hard-to-recover oil. This can be explained by numerous factors, such as a small amount of data on them; no data on the formation and distribution of deposits; a more complex structure; no theoretical basis for the development of bitumen; no fundamental understanding of the displacement of bitumen from the reservoir because of the lack of development experience; impossibility to directly use the design, control and management methods applied in oil fields for bitumen development.

A focused study of Tatarstan’s natural bitumens was commenced in 1970. More than 450 natural bitumen deposits have been identified in Tatarstan in the Lower Permian, Ufimian, Lower Kazanian and Upper Kazanian sedimentary bitumen-bearing sequences of the Permian. These are located in the Melekes trough and on the western slope of the South Tatarstan Arch (Fig. 7). The largest natural bitumen deposits are confined to the Ufimian of the Ashalchinskaya bituminous area. These are bedded deposits with a net pay ranging between several metres and 25-30 m and an occurrence depth of 250-400 m from the ground surface.

The area of current exploration and pilot production operations contains 58 natural bitumen deposits with in-place reserves of about 200 million tonnes. These deposits reside in the Sheshminian/Ufimian terrigenous reservoirs on the western slope of the South Tatarstan Arch.

The pilot application of numerous bitumen recovery methods in Tatarstan for more than 30 years has allowed the selection of the optimal ones and indicated the potential and feasibility of bitumen development using thermal recovery methods, such as in-situ combustion, steam drive, steam-gas drive in combination with wave methods, steam-assisted gravity drive, etc. The borehole development of the Mordovo-Karmalskoye field’s test area by in-situ combustion has allowed reaching an oil recovery of as high as about 35%.

![Fig. 6. Oil production and growth of oil reserves in the Republic of Tatarstan. 1 – Oil production, MM tonnes; 2 – Exploratory drilling, thous. m.; 3 – Growth of hydrocarbon reserves, MM tonnes; 4 – replenishment, %.]

Mastering state-of-the-art flooding development systems has proved to be a real triumph in the creation of the scientific basis for the development of oil fields with the 3 to 5 fold increase in oil recovery in comparison with the previously used natural development regimes. This has taken several decades to achieve. The same success in the development of Tatarstan’s natural bitumens should be attained much faster. Development data on Tatarstan’s bitumen deposits are shown in Fig. 8.

Oil recovery can be maintained by up-to-date, more efficient EOR methods. Formerly, the development of EOR methods in Tatarstan was financed from the Extra-budgetary Fund for the Replenishment of Mineral Resources. Additionally, the Republic of Tatarstan widely used tax incentives for the implementation of tertiary EOR methods. Today, the implementation of EOR methods requires private investments from oil companies. These can be provided by subsoil users on condition that the state guarantees the optimum capital gain. The legislation in effect does not offer such guarantees so far. The required incentives can be given through amendments to the current law «On the Subsoil» or to the Tax Code of the Russian Federation. Otherwise, pilot production using EOR methods shall be financed by the state.

An improved approach to oil recovery issues and incentives to enhance oil recovery in Russia can help produce substantial increments in oil reserves in both newly developed and currently operating fields.

Reference


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