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CLASSIFICATION OF RESIDUAL OIL RESERVES AND METHODS OF ITS RECOVERY

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Abstract

Many oil and gas fields are currently at a late stage of development, while most of them are being developed using flooding. These fields are characterized by the decreasing oil and liquid flow rates and accelerating water-cut. During the development process, the majority of oil reserves are extracted not using methods of production enhancement. Though, oil reserves within undeveloped areas are a valuable source for recovery. To involve residual reserves in active development, it is necessary to make a reasonable justification and a choice of the most effective geological and technical measures that take into account various geological field and well reservoir characteristics. Residual oil reserves at the late stage of development are classified as hard-to-recover and are mainly concentrated in areas not covered by flooding laterally and vertically. They belong to various categories that differ in the geological and technological characteristics. In this regard, it is necessary to plan various geological and technical measures taking into account the structure of residual reserves and patterns of their distribution. Studies of complex oil and gas fields were performed and a detailed analysis of the geological and physical characteristics, parameters of reservoir heterogeneity along with operational, geological and commercial assessment of reserves development were conducted.

Keywords:

Residual oil reserves;
Film oil;
Reservoir;
Geological heterogeneity;
Water-flooding.

1. Introduction

Many oil fields are at a late stage of development and are characterized by a pattern change of residual reserves with the presence of stagnation and undeveloped zones. A variety of reserves and their localization in heterogeneous zones, lens-shaped reservoirs and fields with reduced reservoir properties complicate the process of developing these reserves [1]. The selection of the most effective geological and engineering operations is becoming increasingly difficult [2-4].

2. Problem analysis

Currently, there is no generally accepted concept about the distribution of residual oil in the flooded zone. However, the residual oil reserves in undrained formations are well studied. According to the works of M.L. Surguchev, reserves of residual oil can be divided into the following types (fig.1):

1) oil that remained in low permeability layers and areas not covered by a displacement agent;

2) oil in no-flow area of homogeneous formations;

3) oil that remains in the lens-shaped reservoirs and in areas not penetrated by wells;

4) film oil [5].

Macro-heterogeneous productive formations are deposited under paleo-geographic and facies conditions sedimentation, and it leads to uneven production of reserves aerially and vertically through the oil-saturated interval. Residual oil reserves are formed in no-flow area sediments owing to the fact that heterogeneous formations are characterized by a significant difference in the permeability between layers. Water is easily flowing in high permeability layers and oil is trapped in low permeability zones. Over time, the well that connects to these zones becomes unprofitable due to the high water-cut.

Different structure of deposits leads to different types of recovery mechanism and, as a result, areas of undeveloped reserves are formed. In order to increase an oil recovery, it is necessary to choose a certain method to increase oil recovery. This choice depends on the deposit structure and the recovery mechanism [6].

The second type of residual oil in the no-flow zones of homogeneous formations is formed due to the impact from injection wells. The areal coverage is not full due to a limiting pressure differential [7].

The formation of undrained oil zones is caused by an incomplete well coverage and by changes in the viscosity characteristics at the oil-rock-water boundary. The injected water affects the primary properties of the oil, oxidizes it and changes its properties. Thus, areas of residual oil are formed [7].

The oil viscosity increases when the water is injected; this water has a temperature below the

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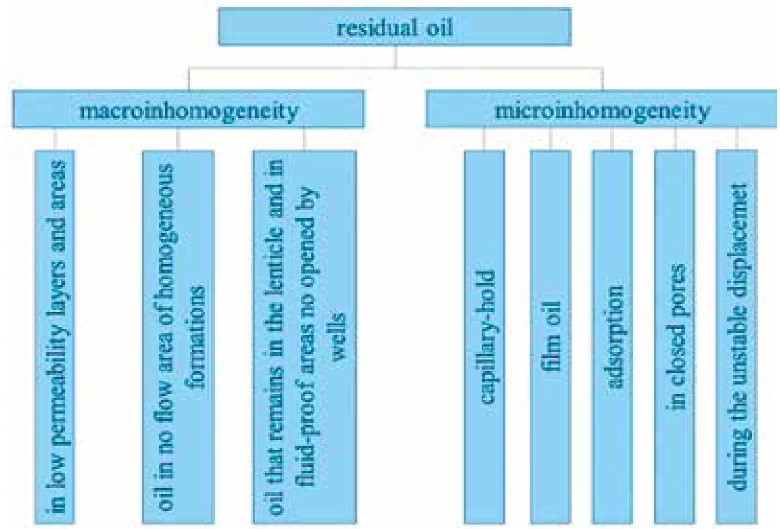

Fig.1. Types of residual oil saturation

reservoir temperature (30-40 °C). This fact can lead to the crystallization of heavy hydrocarbons from oil [8]. The third type of residual oil is formed due to the formation macro-heterogeneity. Formation features that contribute to the lens-shaped reservoir structure and technological aspects of the well placement system contribute to the formation of areas and zones with undrained oil reserves.

The first three types of residual oil are formed due to the reservoir macro-heterogeneity, the fourth type is due to the micro-heterogeneity. The reservoir micro-heterogeneity represents the layers in a more complex structure, and it is a sign of the presence of pores and a conduit of different shape for each layer. The micro level leads to the residual oil reserves formation in conditions of long-term field development using water flooding.

This oil type can be subdivided into capillary-held and film oil. Capillary-held oil is characteristic of a hydrophilic or in part hydrophobic porous environments and is formed in individual pores or in all of them. Their formation is caused by a compression at the place of pore restriction, when the fluid is being displaced.

In order to push the «formed drop», it is necessary to change the drop shape due to the hydrodynamic pressure of the injected water. However, the capillary forces that hold water drops are much greater than the hydrodynamic differential pressure. Film oil is characteristic of hydrophobic reservoirs when bound water is distributed locally in the large pores centers. During the flood displacement process, the injected water is mixed with this bound water and remains in large pores. This oil remains in smaller diameter pores, as well as in large pores in the film form. This residual oil saturation is still able to move and to be extracted during production. The hydrophilic reservoir has a low primary oil saturation and such layers are most effectively developed during the first non-aqueous development period. Oil is displaced by a piston principle. After the beginning of draining, the oil in the reservoir becomes stationary and recovery of this oil becomes very difficult. As a result of flooding of this reservoir type, water is filtered through small and medium pores and oil is pushed into larger pores. Oil located in larger capillaries is displaced by the injected water front.

Compared to a hydrophilic reservoir, a hydrophobic reservoir has a high primary oil saturation and the development of this reservoir type is most effective during the active displacement agent injection. If the oil in a hydrophilic reservoir becomes stationary during oil production, the situation for hydrophobic reservoir is inverse. As a result of reservoir development with layered pressure support, initially hydrophilic reservoir in some areas takes a position with hydrophobic properties and in this case within one deposit there can capillary-pinched, film and strongly bound adsorbed zones formed. The adsorbed oil is stationary. It can be found in hydrophilic reservoirs when the pore surface is covered with a thin layer of oil and water.

Residual oil-saturation of isolated pores and micro-heterogeneity zones are formed in pores with a complex structure and in tortuous capillaries. These zones from the hydrodynamic point of view are not flowing zones of the void volume, and the displacement process by hydrodynamic, capillary forces cannot happen in them [9].

The film oil and oil in isolated pores are difficult to assess by laboratory methods today, so they are determined jointly. Most often, this oil type is formed in a hydrophobic reservoir, but if there are larger isolated pores this oil is formed in a hydrophilic reservoir.

Residual oil saturation occurs during unstable displacement. When developing oil reservoirs, in which the viscosity of oil exceeds the viscosity of the displacing agent, unstable displacement is characterized by the so-called «water fingers» or Safman-Taylor instability [10]. This residual

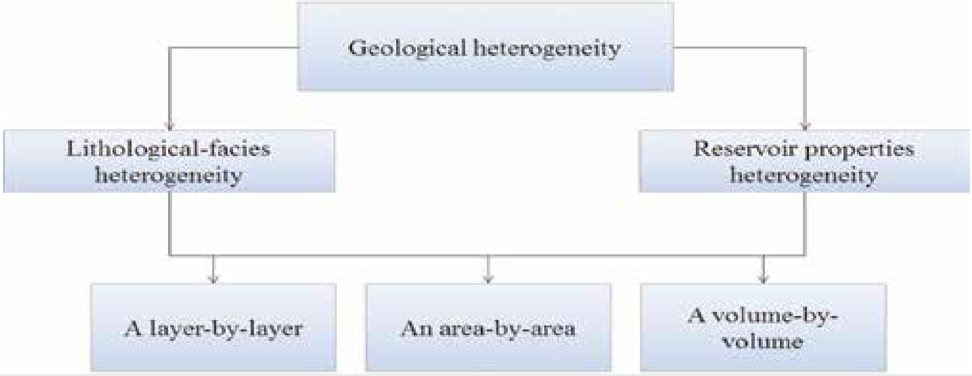

Fig.2. Geological heterogeneity types

oil saturation is characterized primarily by the displacement flow geometric parameters. Equally, the residual oil saturation pattern will depend on the well placement, the distance between the wells and the formation geological heterogeneity [11].

This classification of the residual reserves distribution is quite general and it is not always applicable and universal for all cases. For many fields with variable geological structure and the geological heterogeneity, it is necessary to classify the remaining reserves and consider their geological, geophysical, facies features and the production duration [12].

3. Methods, approach

The reservoir heterogeneity has an impact on the oil production from complex reservoirs and on the formation of residual oil zones.

The definition of oil- saturated rocks «geological heterogeneity» was given in the works of Semin [13]. The most accurate heterogeneity definition is based on the results of Dementiev [14]. Geological heterogeneity can be characterized as a variability of the reservoir rocks physical properties and the components lithological variety of productive layers. Geological heterogeneity can be divided into lithological-facies heterogeneity and reservoir properties heterogeneity (fig.2). The selected heterogeneity types can also be divided on a layer-by-layer, area-by-area and volume-by-volume basis. Lithological-facies heterogeneity is the reservoir composition variability, the variety of granulometric and mineralogical rock compositions, which are expressed in changes of thickness of the composing rocks, pinching out and lenticularity. Lithological-facies heterogeneity is a consequence of rock sedimentation processes of producing layers.

The areal lithological-facies heterogeneity study is possible with the help of maps and layer-by-layer evidence is provided by the geological profiles and sections. Figure 3 shows an example of a lenticular structure. The greatest impact of reservoir heterogeneity on the oil recovery is observed at the late field development stage of. In the process of exploitation of deposits using flooding, the most active and mobile reserves are extracted faster, forming blocks of undrained oil reserves. This displacement is associated with lithological-facies heterogeneity and variability of reservoir properties.

Thus, a detailed study of the reservoir heterogeneity allows the most effective selection of geological - technical operations, which will qualitatively and quantitatively affect the cumulative oil production and technical and economic development indicators.

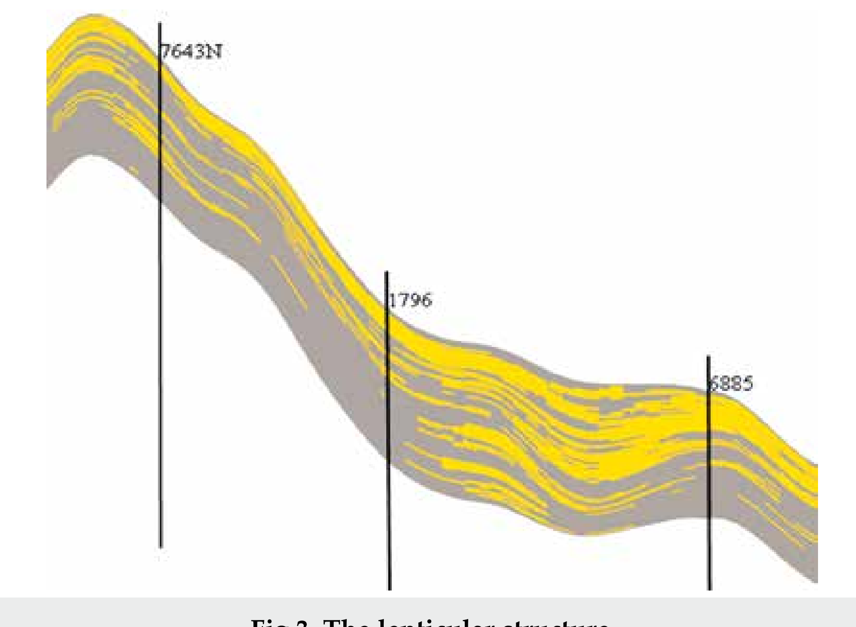

Fig.3. The lenticular structure

4. The influence of lithological facies heterogeneity on the oil production efficiency

The influence of facies on oil reserves production is confirmed by the difference in production rate, difference in facies zones, the achieved efficiency of geological- technical operations and wells' productivity. The research results in this area are reflected in the works of various authors. Many authors in their works show BS group reservoirs and give oil production characteristics through conducting geological- technical operations for various facies.

Authors identified paleo-facial zones of the shelf sea, such as alongshore bars and barrier islands, the head part of rip currents, coastal sediments and rip currents (fig.4). These facies zones belong to the littoral and sub-littoral zones.

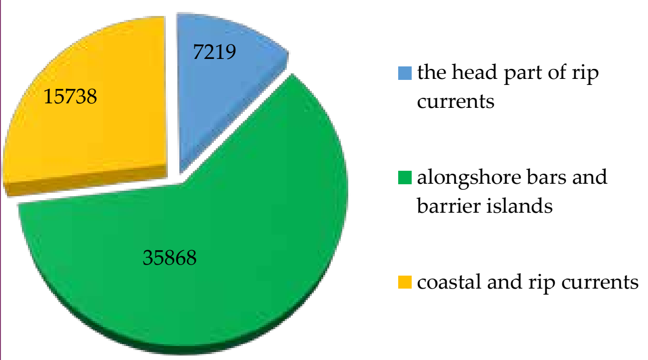

Fig.4. Additional oil production through conducting EOR over a two year period from wells located in various paleo-facial zones

Analysis of the various geological- technical well operations showed preference to locate producing wells in the zones with sediments of alongshore bars and barrier islands. For BS-BV group layers the efficiency of different types of geological, technical operations for selected zones with distinctive paleo-facial features (tabl.1) was studied [15].

Table 1

Geological-technical operations efficiency distribution

№	Activities	Ineffective process, %	Average unit displacement efficiency, tonne/well
1	Hydraulic Fracturing	12	3935
2	Optimization	30	3001
3	RIW	40	1885
4	Forced fluid withdrawal	49	1446
5	SAA	52	1299
6	Mud-acid treatment	71	1098
7	Additional perforation	73	824
8	Acid treatment	74	915
9	Bottom hole treatment	75	641
10	Additional perforation	79	1007
11	Hydro-vibration action	79	677
12	Acoustic action	100	384

Studies for layers BS10 and BV8, which represent a complete second (II) zone cycle, have identified the

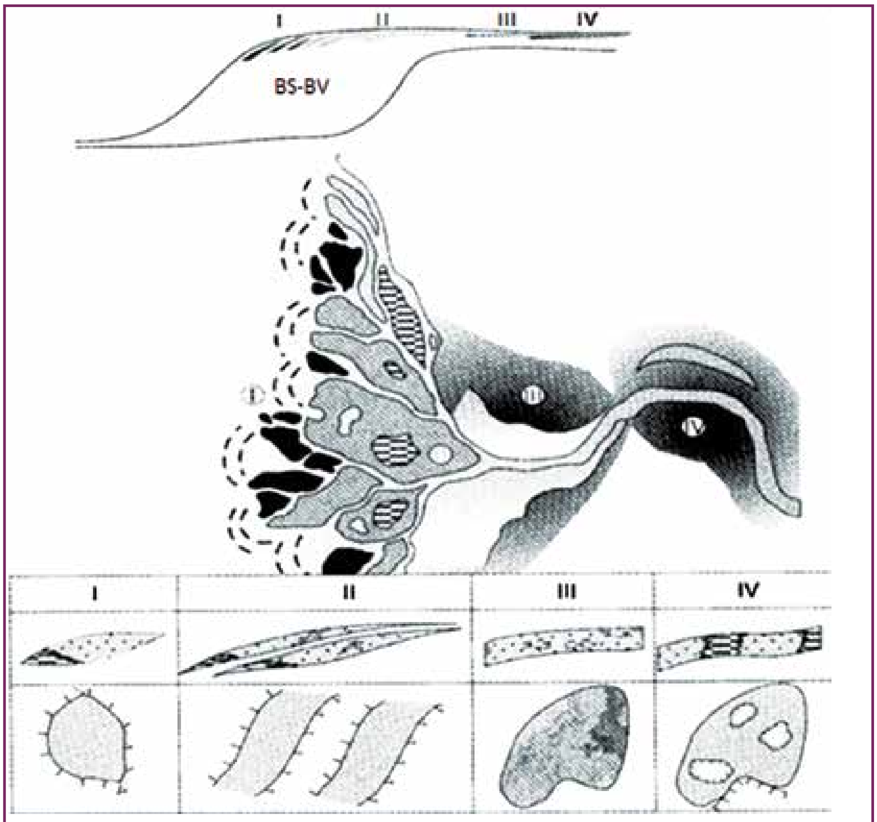

Fig. 5. Genetic conditions of BS-BV reservoirs (Western Siberia)

main facies types (fig.5).

According to the table 1, in the delta paleo-facial areas, hydraulic fracturing methods work well and are the most effective. In the work of [15], it is shown how the geological structure, namely, the reservoir layers conditions and the features of sedimentation directly affect the efficiency of oil influx to the well intensification.

5. Methods for developing residual oil reserves

Recovery enhancement methods are divided into two large groups - the first is aimed at energy support in the reservoir by maintaining reservoir pressure through a system of water injection into the reservoir. The second group are methods aimed at improving oil filtration in the formation well bottom zone.

The two terms, which are commonly used worldwide combining stimulation methods on oil reservoir with the oil production enhancement aim, are EOR (Enhanced Oil Recovery) and IOR (Improved Oil Recovery). The first one mainly includes methods leading to oil recovery enhancement with displacement agent application, other than water (heat, gas, chemical and microbiological methods). The second one includes borehole technologies and other stimulation methods leading to increase in oil production and indirectly to enhanced oil recovery [16].

In other international publications EOR methods are divided based on reservoir rock lithology, which are split into terrigenous and carbonate, and form three groups of methods – thermal, chemical and gas [17].

It is worth mentioning that in Russia due to the EOR ambiguous definition classification methods normally differ in various sources. In some cases, enhancement methods are subdivided into main and supplementary methods [18] or by application criteria (geological-geophysical, technological and material-engineering) [19].

The first group is aimed at increasing the displacement factor and the deposit coverage by water flooding. As a result, wettability is improved, inter-phase tension at the oil-water interface is reduced, pressure gradient is redistributed and capillary forces are enhanced [20].

All known modern reservoir impact methods can be divided into 4 groups, shown in figure 6. The primary methods are based on natural drive mechanisms, maintaining reservoir pressure, that is, using the natural reservoir energy: energy of dissolved gas, elastic energy, edge-water energy, gas cap and gravitational forces.

Secondary methods include techniques for artificially maintaining reservoir pressure using a certain flooding type. These types can be edge-contour and intra-contour flooding. The intra-contour flooding is divided into focal, selective and marginal [21]. Secondary methods also include hydrodynamic methods of increasing oil recovery (forced fluid withdrawal, cyclic water flooding, etc.). Tertiary oil recovery methods are not associated with the development of reserves in the natural mode and do not use untreated water for injection into the formation. These methods are a group of methods that use the mechanism action on the reservoir fluid. Thus, tertiary methods include physical-chemical (injection of sulfuric acid, etc.), physical (formation hydraulic fracturing, drilling of horizontal and second wellbores, vibro-wave action, etc.), thermal (interbed burning, steam treatment, etc.), gas (nitrogen and carbon gas injection, etc.), microbiological (introduction of bacterial products into the layer or their formation directly in the oil reservoir) [22].

Quaternary methods or as they are also called improved oil recovery methods imply a combination of the above-mentioned methods. For each type of residual oil and unique reservoir parameters, a competent selection of geological and technical action is required. Table 2 shows the main known and applied methods for increasing oil recovery and production intensification for each type of residual oil.

It is known that residual oil that is not covered by the flooding process due to the high degree of macro-heterogeneity of the formations under development and stagnant zones is involved in the development by improving the implemented systems and technologies for development and hydrodynamic methods for increasing oil recovery. Residual micro-level oil can be extracted only as a result of various physical and physical-chemical processes [23].

As a result of the analysis and generalization of known studies on the choice of geological, technical actions, authors systematized geological, technical operations for each type of residual oil (tabl.2).

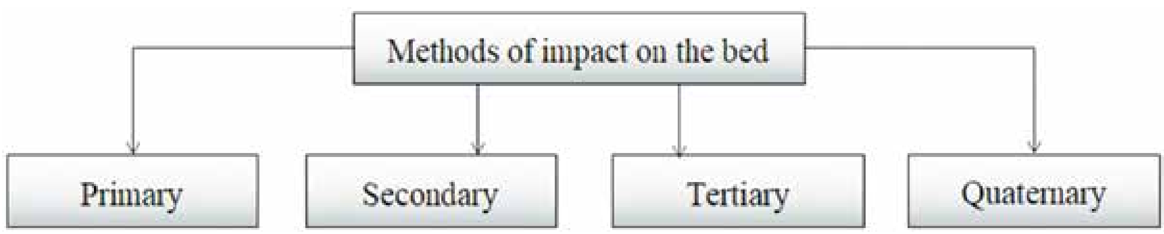

Fig.6. Modern methods of reservoir impact

Table 2

Geological technical measures for different types of residual oil at the macro level

Residual oil type	Recommended technology	Goal
Low-permeability areas that are not covered by the injected water	**Hydrodynamic EOR**	
	Cyclic (non-stationary waterflooding	Pressure changes in injection and production wells lead to a reservoir pressure redistribution. Pressure gradients lead to the formation of new current directions including in areas not previously covered by water-flooding. The increased pressure contributes to the oil compression in low-permeable areas and the injected water is pushed into the reservoir pores. When the pressure decreases, capillary forces hold water in the pores and oil begin to be displaced. Low-permeable layers are involved in the development.
	Changing the direction of filtration flows by transferring the injection	The mechanics of oil expulsion is similar to cyclic water-flooding – when pressure gradients change, the injected water moves into low permeability stagnant zones and oil is displaced. Low permeability layers are involved in the development.
	Forced liquid extraction	Reducing the bottom-hole pressure as the main goal of forced liquid extraction leads to an increase in depression, which contributes to an increase in the producing wells flow rates. Previously undrained reserves and stagnant zones are being involved.
	Hybrid methods	
	Methods for limiting water flows and hydrophobization of the bottom-hole formation zone	The creation of selective blocking of highly permeable layers leads to the increased reservoir coverage by water-flooding. The created “screens” help to redistribute filtration currents and align the displacement front. These actions reduce water-cut and increase the flow rate of producing wells.
	Polymer flooding (injection of cellulose esters, polymer-dispersed systems, colloid-dispersed systems, fiber-dispersed systems)	Polymer flooding methods involve adding water-soluble polymers to the injected water. As a result, the water viscosity increases and its mobility decreases. These aspects help to align the displacement front, slowing its progress in highly permeable zones. The process of filtration currents reallocation is regulated. It increases oil recovery in highly watered layers.
	Displacement of oil by alkaline solutions and compositions	As a result of the alkaline solutions use, the interfacial tension forces are reduced, wettability changes in the oil-rock-water system and oil emulsification occurs. The latter factor helps to equalize the viscosity differences between the oil and the injected water, which helps to increase the reservoir water-flooding coverage. It increases watered layers oil recovery and flattens the intake profile of injection wells.
	Gas methods	
	Water-gas effect	Gas injected under high pressure dissolves in oil and reduces its viscosity. It increases the displacement coefficient.
	Physical methods	
	Hydraulic fracturing	Formation fracturing for this type of residual oil will be most effective when using hydraulic fracturing for wells with a polluted bottom-hole formation zone. This method is one of the most powerful methods. It affects the bottom-hole zone and its remote areas, thereby increasing oil recovery.
Oil in stagnant zones of homogeneous formations	**Hybrid methods**	
	Methods for limiting water breakthrough and hydrophobization of the bottom-hole layers	The creation of highly permeable layers selective blocking leads to the increased reservoir coverage by water-flooding. These created “screens” help to redistribute filtration currents and align the displacement front. These actions reduce water-cut and increase the producing wells flow rate.
	Water diverting agent	As well as limiting water flows, they help to block high permeability intervals by injecting special reagents into injection wells. It equalizes the well intake capacity along the reservoir section and thus creates a more uniform displacement front and reduces water breakthrough in producing wells.
	Physical methods	
	Dilation-wave effects (as well as low-frequency, vibro-seismic effects)	These methods are aimed at reducing water-cut and increasing the reservoir coverage by water flooding in heterogeneous layers using elastic vibration waves. Thus, the bound water (oil) films are destroyed, the bound water is squeezed and produced together with the oil from low permeability interlayers.
	Drilling of inclined and horizontal well bores	It involves in the development previously unexploited reservoir areas. It allows to increase oil production in old fields and increase the oil recovery rate from reservoirs, return to production activity of oil wells that could not be returned to the producing well stock by other methods.

6. Conclusions

Shown are the results of the analysis of the residual oil formation and its recovery.

The initial reservoir saturation depends on the lithological difference and the pore space structure; during the reservoir water-flooding mainly two types of residual oil are formed: at the macro and micro levels. The first oil type is concentrated in non-drained zones, lenses and areas not covered by water-flooding; the second type is residual oil in the pore space.

The oil reserves development and the well productivity depend on the reservoir layers geological heterogeneity, which is the result of the reservoir features formation of lithological - facies character and sedimentation processes.

Geological heterogeneity is demonstrated in the lithological difference of rocks and minerals, changes in the filtration and reservoir properties, aerially and vertically.

Ways to solve the residual oil production challenge are identified.

Geological-technical measures planning for the effective development of residual oil reserves should be based on a detailed study of the geological reservoir structure, including heterogeneity, reservoir lithological facies types and the reserves distribution.

Development of a methodological approach to justify the oil recovery mechanisms on various types of residual oil reserves in order to increase the wells productivity and oil recovery has been presented.

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Классификация остаточных запасов нефти и методов для их извлечения

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Реферат

Большинство месторождений нефти и газа находятся на поздней стадии разработки, многие из них разрабатываются с применением заводнения. Данные месторождения характеризуются снижением добычи нефти и резким увеличением доли обводнённости. В ходе разработки основная часть запасов нефти вырабатывается без использования методов увеличения нефтеотдачи. Запасы нефти в неразработанных зонах являются ценным источником для выработки. Для вовлечения остаточных запасов в активную разработку, необходимо грамотное обоснование и выбор наиболее эффективных геолого – технических мероприятий, которые принимают во внимание различные геологические и коллекторские характеристики месторождений. Остаточные запасы нефти классифицируются как трудноизвлекаемые и в основном сконцентрированы в зонах, вертикально и латерально не охваченных заводнением. Они принадлежат к разным категориям, подразделяемые по геологическим и техническим характеристикам. В связи с этим необходимо планировать различные геолого – технические мероприятия с учетом структуры остаточных запасов и закономерностей их распределения. В работе проведены исследования сложных месторождений нефти и газа, детальный анализ геолого – геофизических характеристик, параметров неоднородности коллектора, а также эксплуатационная, геологическая и коммерческая оценка разработки запасов.

Ключевые слова: остаточные запасы нефти; пленка нефти; коллектор; геологическая неоднородность; заводнение.

Qalıq neft ehtiyatlarının təsnifatı və onların çıxarılma üsulları

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Xülasə

Neft və qaz yataqlarının əksəriyyəti işlənmənin son mərhələsindədir, onların çoxu suvurma üsulu ilə işlənilir. Bu yataqlar neft hasilatının azalması və sulaşma payının kəskin artması ilə xarakterizə olunur. İşlənmənin gedişatı zamanı neft ehtiyatlarının əsas hissəsi neftveriminin artırılması üsullarından istifadə edilmədən hasil olunur. İşlənməmiş zonalardakı neft ehtiyatları qiymətli hasilat mənbəyidir. Qalıq ehtiyatların aktiv işlənməyə cəlb edilməsi üçün yataqların müxtəlif geoloji və kollektor xarakteristikasını nəzərə alan effektiv geoloji-texniki tədbirlərin düzgün əsaslandırılması və seçimi zəruridir. Qalıq neft ehtiyatları çətin çıxarıla bilən ehtiyatlar kimi təsnif edilir və əsasən suvurma ilə əhatə olunmayan zonalarda vertikal və lateral olaraq cəmlənir. Geoloji və texniki xassələrə əsasən onlar müxtəlif kateqoriyalara aid edilirlər. Bu səbəbdən, qalıq neft ehtiyatlarının quruluşunu və paylanma qanunauyğunluqlarını nəzərə alaraq müxtəlif geoloji və texniki tədbirlər planlaşdırmaq lazımdır. Məqalədə mürəkkəb neft və qaz yataqlarının tədqiqatı aparılmış, kollektorların geoloji və geofiziki xarakteristikaları, qeyri-bircinslilik parametrləri ətraflı təhlil edilmiş, həmçinin neft ehtiyatlarının işlənməsi istismar, geoloji və kommersiya baxımından qiymətləndirilmişdir.

Açar sözlər: qalıq neft ehtiyatları; neft pərdəsi; kollektor; geoloji qeyri-bircinslilik; suvurma.