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SPECIFICS OF GEOLOGICAL STRUCTURE AND OIL RESERVES RECOVERY IN HETEROGENEOUS RESERVOIRS OF PERMIAN-BASHKIRIAN DEPOSITS

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Permian-Bashkirian arch fields are characterized by non-uniform recovery of oil reserves, which could be associated with hard-to-recover reserves. Main part is formed by deposits with small oil net pay, low values of permeability, porosity and high viscosity. Accomplished analysis and juxtaposition of reserves recovery maps with heterogeneity maps allow to identify zones with the highest expected coefficients of oil recovery, which is a priority in field development designing.

Keywords: *oil reserves, permeability, porosity, oil saturation, terrigenous reservoir, carbonate rocks*

Designing and methodology selection of a concept and technology for hydrocarbon fields development conforms to a set of defined rules. The result of the successful development plan could be the maximum achievable oil recovery factor along with satisfactory technical and economic parameters. In conditions of the routine completion of project documents for fields development and their dependence on regulations, it is not always possible for any particular field to choose the appropriate development plan, technology, aiming to increase the reservoir recovery, and to carry out the objective geological, hydrodynamic and geostatistical modelling. This is due to the lack of sufficient analysis and not full examination of the geological and technical information.

Oil fields of the central and eastern parts of the Ural-Volga region are characterized by significant variety of geological conditions, oil reserves recovery ratios and efficiency of stimulation methods application. Significant volume of information has been collected on the geological and technical conditions of oil fields exploitation in this area. The studied oil fields significantly differ in terms of geological, physical and chemical characteristics, oil and gas reserves, existing practice, methods and technologies of their development.

Significant oil reserves of central and north-eastern parts of the Volga-Ural province are located within Permian-Bashkirian arch (PBA). In total volume of the

mentioned region, part of initial geological and recoverable reserves PBA is accounted for 16 and 14 %, respectively (Fig. 1). Within the borders of the studied structural tectonic element there are 81 oil and gas fields are being developed, including large, such as Kokuiskoe, Krasnoyarsko-Kuedinskoe, Pavlovskoe, Chetyrmanskoe, Shagirtsko-Gozhanskoe and Yugomashevskoe.

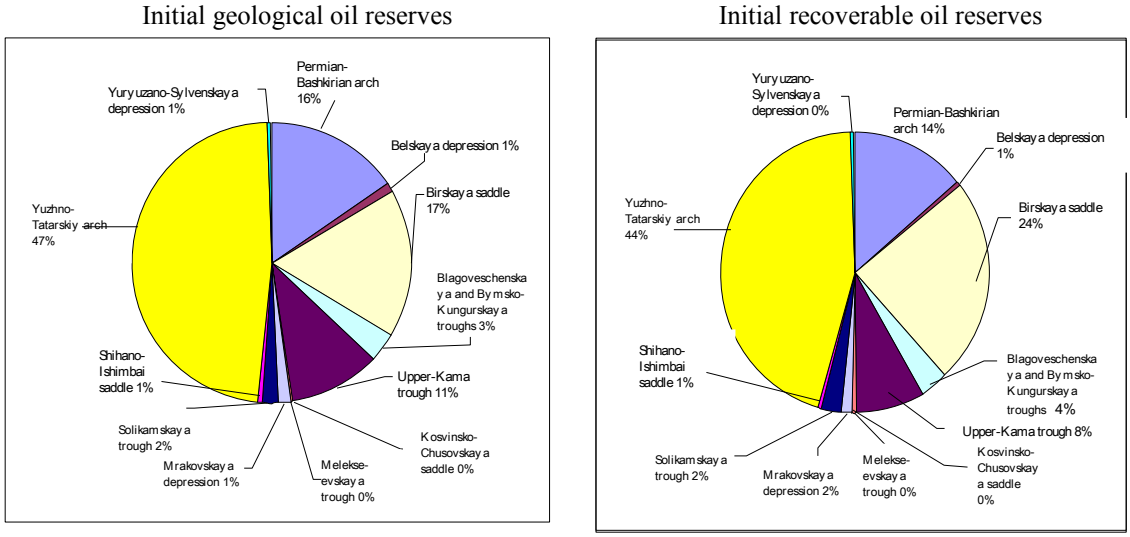

Figure 1. Oil reserves distribution according to tectonic elements

Permian-Bashkirian arch represents a fairly complex architecture. Based on Permian deposits Bashkirian uplift can be clearly identified as a single structure. It has borders with Pre-Ural trough to the east, with Upper Kama depression to the west, with Babkinskaya depression to the north and Aktanysh-Chishminskiy trough to the southwest. Arch transfers to Blagoveschenskaya depression in the south. Within the delineated borders its length reaches 370 km with the width of 100-160 km. Devonian and Carboniferous horizons are presented by two uplifts: Permian and Bashkirian, divided by Babkinskiy trough. These uplifts are regionally oil-bearing [1].

Each structural element forming Permian-Bashkirian arch has specific features of stratigraphic and lithological structure of sedimentary cover. In recent years Permian-Bashkirian arch is being subdivided by separate and distant from each other two structural forms – Permian and Bashkirian arches. Bashkirian structure is characterized mostly by almost complete absence of Devonian terrigeneous reservoirs in the eastern part, Vendian thicknesses reduction and abrupt increase of the Riphean deposits thick-

nesses. In the north and north-western directions thicknesses of terrigeneous Devon and Vend are increasing, whereas Riphean abruptly decreasing. Thus, Babkinskiy trough is characterized by presence of thick sequence of terrigeneous rocks within Lower Carboniferous, with thicknesses abruptly reducing in the southern and northern directions.

Within the boundaries of Permian uplift the most widely spread oil-bearing strata is Visean. There has been identified the most productive deposits. There are few zones of oil and gas accumulation towards the top of the structure, associated with uplifted parts-ridges: Krsnokamsko-Polaznenskaya, Mezhevskaya, Kamennolozhskaya, Lobanovskaya, Osinskaya and Palskaya. There are common features in tectonic structure of traps for fields of one oil and gas zone as well as confinedness of oil and gas occurence to the same productive horizons, similar lithologic and facies characteristics each of these strata within the whole zone (ridge) and also uniformity of reservoir type, saturated oil and gas.

Within Bashkirian structure of the Permian-Bashkirian arch commercial quantities of oil and gas have been identified in Mazuninsky, Veslyanskiy, Kuedinskiy, Dubovogorskiy, Chernushenskiy, Uinskiy, Dorokhovskiy, Taushskiy, Kaltasinskiy ridges of Chaikinskiy, Aiskiy, Ust-Aiskiy and Kushkulskiy uplift zones, Batyrbaiskiy structural bench. These tectonic structures are complicated by local uplifts which control oil and gas deposits [1].

Following K.S. Baimukhametov [2] and R.G. Galeev [3] oil reserves development located in tectonic regions of Yuzhno-Tatarskiy, Permian-Bashkirian arch as well as in the Birskaya saddle and Upper-Kamskaya trough vary within the range 74-94 %, in other tectonic regions yet developed less than a half of initial potential oil and gas resources. Productive strata of Bashkortostan have developing rate from recoverable oil reserves in terrigeneous Devon, terrigeneous Lower Carboniferous and carbonates of Lower Permian more than 80 %, for other oil and gas systems vary from 23 to 52 %.

Recovery ratio of productive beds of one stratigraphic subdivision in different tectonic structures varies within wide range. Among geological factors that have effect on oil recovery efficiency are complexity of deposits geological structure, low-permeability, low-porous, heterogeneous reservoirs, small oil net pay, high oil viscosity and wide oil-water zones.

Large fields related to the Permian-Bashkir uplift are described by a non-uniform oil reserves recovery. Most of these deposits are associated with the terrigenous strata of the Lower Carboniferous. Remaining reserves of these deposits are considered as hard to recover and are concentrated in traps, confined to the upper parts of the local uplifts with high-productive horizons and lenses. Besides that, the majority of oil deposits of the Middle and Lower Carboniferous have an extensive water-oil zone.

Subject of oil reserves distribution within productive layers has been studied many times, and mostly it was related to oil reserves of administrative occurrence, e.g. Republic of Bashkortostan and Perm region separately. In Paleozoic, within Permian-Bashkirian arch main geological and recoverable oil reserves are located in Upper and Middle Carboniferous deposits, 50 % – initial geological reserves and 57 % – initial recoverable reserves and in terrigeneous strata of Lower Carboniferous (27 and 24 % respectively). In productive layers of Devonian there are about 10 % of geological and recoverable oil reserves (Fig. 2).

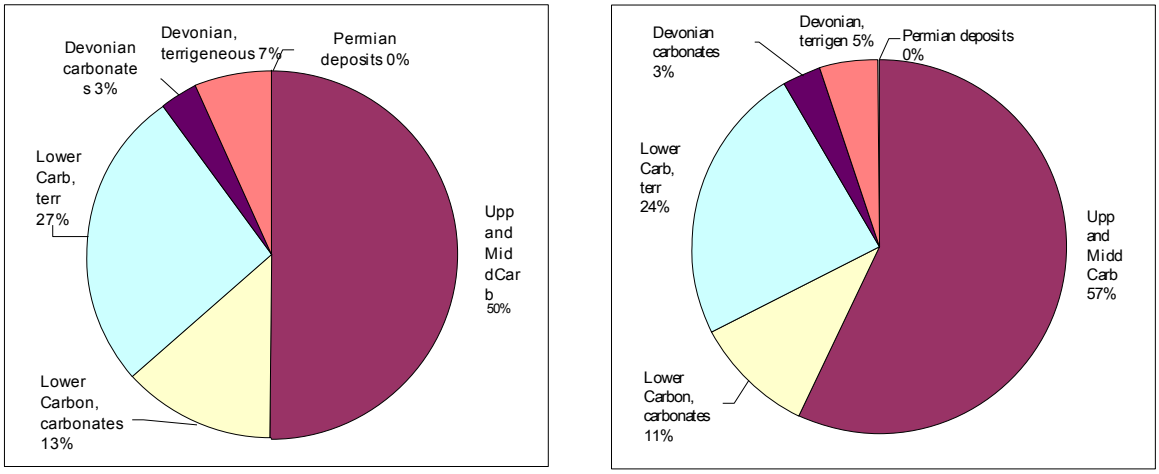

Figure 2. Oil reserves distribution according to productive strata

Analysis of the oil reserves structure of the Permian-Bashkir uplift has revealed that more than a half of reserves in the terrigenous strata, 56 % of the initial recoverable reserves (IRR), are related to the hard to recover reserves (Table 1). About 55 % of the hard to recover reserves (HRR) are associated with beds which have the oil net pay less than 2 m. Low-permeability reservoirs contain 31 % IRR out of all HRR. Oil with the viscosity more than 30 mPa·sec accounts for the fourth part of HRR in a group of the initial geologic reserves. Initial geologic reserves (IGR) depletion and IRR depletion come up to 50 and 41 % of HRR, respectively.

Table 1

Structure and reserves recovery degree of Permian-Bashkirian arch fields

Criteria of Hard-to-Recover Reserves	Reserves Group	Part of HRR, %
Productive deposits in terrigeneous reservoirs		
Total, %	IGR	58
	IRR	56
Reservoirs with oil net pay < 2 m	IGR	41
	IRR	55
Reservoirs with porosity < 8 %	IGR	0,1
	IRR	0,1
Reservoirs with permeability < 0,03 μm^2	IGR	23
	IRR	31
Reservoirs with oil viscosity > 30 mPa·s	IGR	25
	IRR	12
Reservoirs with temperature < 20 ºC	IGR	3
	IRR	2
Reservoirs with REF > 70 %	IGR	50
	IRR	41
Productive deposits in carbonate reservoirs		
Total, %	IGR	68
	IRR	72
Reservoirs with oil net pay < 4 m	IGR	91
	IRR	99
Reservoirs with porosity < 8 %	IGR	5
	IRR	2
Reservoirs with oil saturation < 55 %	IGR	6
	IRR	3
Reservoirs with permeability < 0,03 μm^2	IGR	46
	IRR	46
Reservoirs with oil viscosity > 30 mPa·s	IGR	12
	IRR	8
Reservoirs with temperature < 20 ^{0}C	IGR	15
	IRR	9
Reservoirs with REF > 70 %	IGR	36
	IRR	48

Hard to recover reserves associated with carbonate reservoirs have a significant part (68 % of IGR and 72 % of IRR) in the structure of total reserves. Almost all HRR are contained in beds with the thickness less than 2 m; besides, there is a significant por-

tion of HRR in low-permeability reservoirs (46 %). High-viscosity oil reserves account for 12 % of IGR and 8 % of IRR. About 48 % HRR are reserves of the fields, which have the recovery more than 70 % of IRR.

Within the Permian-Bashkir uplift there are oil deposits, which have oil net pay less than 55 %, porosity less than 8 % and reservoir temperature less than 20 ºC.

Therefore, a significant part of the hard to recover reserves over the Perm-Bashkir uplift make the deposits, described by low oil net pay, low numbers of permeability coefficient, oil of high viscosity and reserves efficiency factor (REF) more than 70 %.

Main productive reservoirs of the studied area are oil deposits of Bashkirian age and Yasnopolyanskiy horizon. Data analysis presented in Table 2 shows that main reserves and main recovery take place from productive beds of Yasnopolyanskiy suprahorizon (Tl2-a, Tl2-b, Bb1, Bb2) of Bashkirian age (Bsh1, Bsh2).

Table 2

Geological and technological parameters of the studied area

Parameters	KV1+V3V4	Bsh	Yasn	T	D1	Total
Recovery rate from IRR, %	0.4	0.83	0.7	0.2	0.05	0.68
Water-cut, %	31.2	60.9	88.5	61.6	25.3	78.7
Compensation of recovered fluid in reservoir conditions: current, %	13	153	41	8.4	-	67
cumulative, %	2.3	161	135	221	-	131
Average daily production rate of one producing well: oil, t/day	4.7	2.7	4.3	1.2	0.9	3.1
fluids, t/day	6.4	6.9	37.0	3.2	1.2	14.7
Average daily injection rate of one injection well, m^3/day	67.7	103	117.1	31.1	-	107
Oil recovery from initial geological reserves	2.1	16.5	18.4	8.4	1.8	14.0
from recoverable	10.3	52.4	58.4	28.1	7.2	47.6

Analysis of oil reserves recovery from Bashkirian age layers over certain areas has revealed that there are zones in the north that are being actively developed, where development plan has been formed. In average over the area geological reserves recovery is 22 %, values of current oil recovery coefficients for wells vary from 0.02 to 70 %.

On the areas of deposits with active system of reservoir pressure maintenance and high oil production rates there is an increase of water-cut in well production. In average water-cut is accounted for 62 % over the area and varies from 0 to 98 %.

In total increase of reserves recovery ratio makes water-cut ratio higher as well, meanwhile, there is a prominent group of wells with low recovery and high water-cut. This category of wells is situated in zones of injection wells influence. Geological oil reserves recovery of the central part has reached 19.7 % in average. The highest values of current coefficient of oil recovery (COR) have been noted in zones which are the most fully affected by injection with favourable reserves characteristics and high initial geological reserves. Values of current COR reach here 40-83 %. Over the southern area 9.5 % from initial balance reserves have been recovered.

Most of the wells are characterized by recovery of 5-15 % with water-cut of well production up to 40 %. Several wells in oil-water zones have geological reserves recovery up to 15 % and high water-cut in wells – from 80 to 100 %. There is a tendency within the whole area of the premature increase of water-cut with low recovery rate, especially in large oil-water zones and areas with injection wells of high layer-by-layer heterogeneity. The highest reserves recovery is noted in the north-western area within the zones of high oil net pay.

The maximum value of current coefficient of oil recovery for productive beds of Yasnopolyanskiy suprahorizon of the northern area reaches 75 % and in average for wells is 24 %, over the whole area initial geological reserves have 19.8 % recovery, while current water-cut over the area has reached 84 %. Current coefficient of oil recovery for the central area is 1.6 %. Values of current COR for wells (including abandoned) vary from 0.03 to 78 %. Over the southern area about 9.1 % of geological reserves have been produced. Current coefficients of oil recovery for wells vary from 0.09 to 63 % and in average is 21 %. Moreover, with the recovery increase there is an increase of water-cut in well production, for most of the existing wells it exceeds 40 %.

Geologic-production analysis of the recovery of particular fields in the studied tectonic structure, including integrated analysis of maps of remaining reserves, water cut, oil net pay, productive beds extension and reservoir properties has revealed the following specifics of fields exploitation:

– a distinct increase in water-cut has been indicated in carbonate deposits of the Bashkirian age, particularly in wells situated in extensive water-oil zones (WOZ) and in zones adjacent to the injection front with high layer by layer heterogeneity. Drilled out parts of deposits with favourable reservoir properties and high initial geologic oil reserves are effectively being recovered;

– due to a significant variability of geologic and physical characteristics of beds represented by terrigenous strata of the Lower Carboniferous, the recovery of oil reserves areally and in cross-section has a non-uniform character. Effective recovery takes place in Bobrikovskian horizon: beds Bb1 and Bb2. All beds of Tula and Bobrikovskian horizons have low reserves recovery in WOZ. High variation of geological and physical parameters of productive beds affected producing capacity of certain parts of the deposit, subsequently creating zones with significant remaining reserves;

– Tournaisian age deposits are described as low recovery horizons. High results of current oil recovery coefficients in wells are being observed in good drained zones with significant values of permeability, porosity and specific geologic reserves [4, 5].

Hence, the detailed geologic and technological analysis made it possible to define that the areal and layer by layer heterogeneity has the substantial influence on efficiency and uniformity of reserves recovery. In this situation, while working on the development plan, a careful attention should be paid to a qualitative and quantitative influence of heterogeneity on hydrocarbons production efficiency.

It is known that complexity of geological structure of a field is often described by unfavourable reservoirs, such as: low-permeability, low-porosity, discontinuous, highly segmented beds, beds with small net oil pay and low oil saturation, beds with dual porosity and permeability. All outlined parameters, to a greater or lesser extent, have an impact on a degree of oil reserves recovery. In order to find out and identify the influence of reservoir properties on the reserves recovery degree from the Yasnopolyanian superhorizon, geological-statistic models of influence of the heterogeneity parameters, cumulative oil production maps, water-cut maps, and porosity, permeability, oil saturation and compartmentalization maps have been built.

With the aim of quantitative and qualitative valuation of influence of the heterogeneity parameters, the geological-statistic modeling has been undertaken, which included building regression models and their analysis. As parameters of heterogeneity of the

productive beds affecting the development efficiency the following coefficients were used: compartmentalization and variation of the oil saturated thickness, permeability, porosity and oil saturation. As a dependent parameter, values of dispersion and variation of the cumulative oil production, oil production rates, water production rates and water cut have been chosen.

Accomplished analysis and reserves recovery maps correlation with compartmentalization maps along with the geological-statistic modeling for the geological and physical conditions of a large field of the Permian-Bashkir uplift made it possible to accurately determine parameters of heterogeneity, which have the biggest impact on the degree of reserves recovery, which is permeability and porosity variation.

Using this approach, it looks possible to predict what particular parameters of heterogeneity affect the degree of reserves recovery, and also to find zones with the highest predicted oil recovery coefficients, what in our mind is the priority while working on the field development plans and what should be considered in hydrodynamic modeling.

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