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SUBSTANTIATION OF FLUID SATURATION OF RESERVOIR-ROCKS ON THE BASIS OF PETROPHYSICAL STUDIES

The movement of formation fluids in porous medium is essentially caused by its structural parameters. Numerous attempts to establish analytical connection between permeability and porosity of rocks usually didn't give the desired result, that′s why closeness of established dependencies between them was intensified by introducing additional parameters, such as pore canals curving, structural and lithological coefficients etc. The values of these parameters were defined empirically and only for certain rock-reservoir models, that's why their application for wide spectrum of rocks natural features is very problematic.

Experimental investigations carried out in L′viv department of L′viv State Geological Research Institute over finding out the ratio between hydraulic and electric curving (similar physical notions) on glass capillary models of various forms: direct, with different curving coefficients, with one-side open pores and widened pores. According to gained results no identity between electric and hydraulic curving of pore canals was observed. Depending on capillary shape the ratio between them changes from 3 to 12 times. Eventually, this is caused by the fact that water-saturated capillary models, in addition to surface conductivity they can have electron conductivity, which are practically impossible to differentiate. That's why the use of given parameters doesn't give us any objectivity as to the characteristic of porous medium structure.

Due to this, we have developed the methods of quantitative estimation on the micro level of porous space parameters. According to curves of capillary pressure (CCP), the total volume of oil and gas reservoirs porous space is divided into the following parts:

$$C_a + C\Delta_p + C_c = 1,$$

where:

C_a – the part of hypercapillary pore canals;

$C\Delta_p$ – the part of capillary pores;

C_c – the part of subcapillary pores.

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Hypercapillary pore canals C_a – are the volume part, filled with pores, from which fluids displacement occurs without the effect of capillary forces (piston displacement of hydrocarbons). These are mostly, pore canals with radius 10–100 mkm and mostly with neutral surface wettebility(the beginning of capillary pressure curves).

Capillary pores $C\Delta_p$ are the part of porous medium volume, filled with pore canals of 1–10 mkm radius, fluid displacement efficiency from which depends on the ratio of hydrodynamic and capillary forces and the character of porous surface wettebility (transient stage of CCP). Subcapillary pores C_c are the part of the volume, made up of non-filter pores with radius less than 1 mkm (the end of CCP), which are usually filled with residual water. Due to these stages the efficient porosity C_{pe} can be written in the following way: $C_{pe} = C_p(1–C_c)$, dynamic C_{pd} – as $C_{pd} = C_p(1–C_c – C\Delta_p)$. Taking this into consideration, for oil and gas fields the coefficient of oil (gas) displacement is written in the formula $\beta = C_{pd}/C_{pe}$. The offered methods give us the possibility to evaluate the effect of porous medium structure parameters on capacitance and oil and gas recovery features of reservoirs.

With an aim to find out the reasons of residual water-saturation values deviation Crw from permeability Cper and established between them correlation dependency, two groups of rocks in Turnei deposits of Rudivka and Svyrydivka fields of DDD were researched: a) with similar values of permeability, porosity and different character of pore canals surface wettebility; b) with similar values of permeability, porosity and with identical wettebility.

Special feature of researched rocks with different wettebility is that CCP of hydrophilic and hydrophobic samples differs greatly. So, effective and dynamic porosity of rocks are caused by the porous space structure and wettebility of pore canals surface, which should be taken into account while studying oil and gas rock-reservoirs.

The researched sandstones had different surface wettebility and cement types: carbonate, anhydrite-carbonate-clay, clay-siliceous- carbonate, and also they differed in porous space structure, which had a certain effect on the formation of hypercapillary, capillary and subcapillary pores part. Samples with identical wettebility were hydrophilic, but they differed in porous space structure. In each concrete case, the significant effect gained those or others rocks features, that actually explain the deviations of certain measurements of residual water-saturation from average correlation. Low water-saturation (20–25%) is connected with hydrophobisation of certain pore canals surface and carbonate cement, which is soaked with hydrocarbons, the presence of isometric pores, the size of which is more than 100 mkm, and open fissures, which are proved by lithological research of rocks in microsections. High values of water saturation (80–90%) are caused by peculiarities of rock porous medium structure: low content of hypercapillary (6%) and capillary (6%) pores and high content (88%) of subcapillary pores, which have no filtration.

The object of further investigations were core samples, selected from Cretaceous deposits of Lopushnia field (Precarpathian oi and gas bearing region) and Tournaisian deposits of Lychkiv field (Dnipro-Donets gas-bearing region).

The formation model, which is 0.48 meter long, and 0.029 meter in diameter, with 32% of residual water saturation in Lopushnia field ,was characterized by the following average parameters: 13.6% porosity, $59.9 \cdot 10^{-15}$ m^2 permeability. The conditions of the experiment were maximally approximated to the formation conditions. It was detected that basic oil volume was displaced during water-free period – 0.51. Further water injection insignificantly changes the coefficient of oil displacement, which rises to 0.53 at washing multiplicity 4.1, and in case of endless water injection it rises up to 0.55. The oil recovery coefficient ,taking into account water-injection coverage, will be approximately 0.34. The results of the experiments showed that depending on filtration properties and character of rocks wettebility during water-free period of exploitation from Low-Cretaceous deposits of Lopushnia field 53–57% of oil can be recovered, 22–30% of oil is in a film state, 21% is adsorbed oil (relative to oil-saturated volume of pores.)

Similar experimental investigations were carried out on the formation model which is 0.31 meter long, 0.029 meter in diameter and which has 21% residual water saturation with average porosity 9.6% and permeability $20.6 \cdot 10^{-15}$ m^2, selected from rock samples of T-3 horizon of Lychkiv field in Dnipro-Donets depression. The displacement coefficient during water free period was 0.523, after 3–4 times of porous space model washing with service water it was 0.683, and under endless water injection it was – 0.69. The oil-recovery coefficient for this horizon, taking into account water flooding coverage ,is prognosed on the level of 0.444.

The determination of oil-displacement coefficient using standard methods (39-195-86) – is very technically-complicated process, which requires the expenditure of much labor. Due to this we offer express method, the main aim of which lies in conducting capilliarymetric investigations in centrifugal field. This method is approbated on the Juliyiv core samples (Horizons V-20–21, V-25–26), of Lopushnia (Lower Cretaceous) and Hirkaliay (Middle Cambrian deposits) fields.

The comparison of the results, gained from express method and on filtration plant with modeling of formation thermobaric conditions, showed that the relative error, as a rule, doesn't exceed 3%. The advantages of the offered methodology are also possibilities of differential determination of replacement coefficient depending on filtration-capacitive properties and wettebility of reservoir-rock surface.

The differentiation of oil-saturation on residual and by oil movement rate in reservoir-rocks has very big importance, as the efficiency of oil recovery increase significantly depends on it.

We've theoretically substantiated and offered a new methodology of reservoir-rocks oil saturation structure determination (patent of Ukraine 33113, Branch Ukrainian Standard 41-31-2002), which takes into account forces of water and oil molecular interaction with porous medium. Our methodology foresees the detailed investigation of filtration-capacitive and surface-active properties on core samples, conducting capillarymetry with getting curves of water and oil saturation C_w, C_o relations from displacement pressure p, the differentiation of displacement conditions on every regime ,building differential curves of water and oil displacement at residual water depending on given relatively to initial pressure of displacement $\overline{p}$. According to typical dots on differential curves there is oil-saturation division C_s into zones, which take into account energy of fluid relation with porous medium surface.

For horizons V-20–21, V-25–26 of Yuliyiv field in Dnipro-Donets Depression using our methodology (Branch Ukrainian Standard 41-31-2002) such quantitative ratios of reservoir-rock oil-saturation structure were established: oil in free state 23–45%, oil in film state – 28–30%, in adsorbed – 10–22% (relatively to total pores volume).

With an aim to study reservoir-rocks changes depending on displacement conditions the experimental investigations were carried out with the usage of new pairs – emulsifier-agent "Emir" and blocking-agent "Emir-B" (I. B. Hubych, 2004) on the sandstones of Lower Cretaceous deposits of Lopushnia oil field (Precarpathian oil-and-gas bearing region), which are characterized by 13,5% porosity, and about $15 \cdot 10^{-15}$ m^2 permeability. It is established that after blocking of hypercapillary pores the displacement coefficient depending on gradient pressure (1–6.6 MPa/m) changes from 0.51 to 0.82, which proves the displacement of film oil, which is concentrated in capillary pores with radius less than 10 mkm. So, oil in film state should be considered as potential reserve of oil recovery increase at certain filtration properties of rocks, their wettebility and gradient of displacement pressure using certain technologies.

On the example of Middle-Cambrian reservoirs of Hirkaliay field (Baltic oil region) the petrophysical base of oil saturation differentiation was developed acc. to oil and porous medium interrelation rate (relatively to total pores volume), which takes into account filtration-capacitive and electric rock properties (moisture parameter – porosity parameter multiplied by saturation parameter $P_p \cdot P_s$) (Fig. 1).

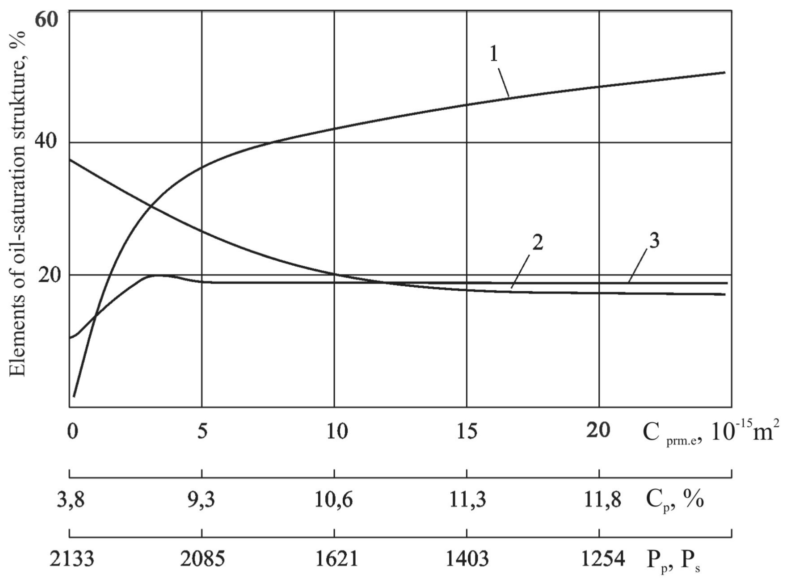

Fig. 1. The dependency of reservoir-rock oil saturation structure from effective permeability, open porosity and moisture parametr. Hirkaliay dield, Middle Cambrian desposits.
Oil: 1 – free, 2 – film, 3 – absorbed

It is established that on the average, relatively to effective pore volume, 37% of oil is in free state, 37% of oil is in film state and 26% of oil is in adsorbed state; this is equal to the average value of rock porosity 8.2%, phase permeability $2.6 \cdot 10^{-15}$ m^2 and residual water saturation 24%. From experimental calculations of oil displacement coefficient by formation water, the oil recovery coefficient on the 0.47 level was substantiated.

The investigations carried out on the pore-fissured formation model which is made up of Middle-Cambrian rocks of Shiuparai field (Baltic oil-bearing region) showed that reduction of formation pressure during pool development will have very weak effect on the change of effective permeability for oil. In this type of reservoirs the filtration occurs mostly through fissures, and from pore space only oil is displaced, which is in free state. The increase of pore washing with water doesn't cause a significant enlarging of oil recovery volume. The coefficient of oil displacement by water during water free period was 0.4 for effective pores washing multiplicity of model 0.79 the coefficient was 0.44, and for 6-times washing it increased slightly(to 0.49). The coefficient of oil recovery is prognosed to be on the level of 0.29.

In case of water saturation of formation model on the level of 52–54%, oil phase permeability is practically zero, and strata water at water saturation 35–60% oil phase permeability decreases in 2–3 steps. Reservoir-rock oil saturation changes from 74 to 81%. Oil saturation structure is distributed relatively to total pore volume in the following way: oil in free state – 27–51%, film oil – 24–31%, adsorbed oil – 6–18%.

CONCLUSIONS

The results of experimental investigations on the capilliars of various forms didn't prove the identity between electric and hydrodynamic pore canals curving. That's why, in development of model concepts about porous medium structure we should refuse from using these parameters.

On the basis of core investigations carried out from productive deposits of various oil and gas bearing regions, for the first time heterogeneous wettebility of reservoir-rocks was experimentally proved. It is established that the most vividly molecular – surface effects become apparent in rocks with permeability less than $1 \cdot 10^{-15}$ m^2.

The method of quantitative estimation of porous medium structural parameters by distinct areas of capillary pressure curves was proposed according to which the part of hypercapillary, capillary and subcapillary pores is being determined. Their relations to great extent stipulate the character of reservoir-rocks saturation with formation fluids.

The differentiation of oil in reservoir-rocks according to stage of its movements (patent of Ukraine 33113, Branch Ukrainian Standard 41–31–2002) is carried out due to oil displacement parameters taking into account hydrodynamic and capillary forces. This gives possibility to advance arguments of oil fields recoverable reserves.