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The Properties of Granular, Fractured and Cavernous Reservoir Rocks

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Abstract: The formalization of relationships between three parameters characterizes all structures of the pore space: coefficients of porosity, permeability and residual (stable) fluid saturation. Statistical analysis of the laboratory data of collectors allowed to define the "slip" of the water saturation depending on the porosity, and the range of changes — on permeability in the direction of residual water growth. At the same porosity and permeability of samples identical values of residual water saturation are natural, but they do not depend on the lithology of the mineral skeleton. Regularity of going beyond the usual properties of water and oil saturated industrial reservoir rocks and beyond water and oil pressures having diffusion permeability was detected.

Key words: reservoir rocks, the structure of the pore space, formalization of three parameters of collector

1. Introduction

The formalization of relationships between three parameters characterize all structures of the pore space: coefficients of porosity, permeability and residual (stable) fluid saturation. Statistical analysis of the laboratory data of collectors allowed to define the "slip" of the water saturation depending on the porosity, and the range of changes — on permeability in the direction of residual water growth. The same porosity and permeability of samples correlates with the identical values of residual water saturation, but they do not depend on the lithology of the mineral skeleton. There was detected the regularity of going beyond the usual properties of water and oil saturated industrial reservoir rocks and beyond water and oil pressures having diffusion permeability.

2. The Characteristics of Reservoir Rocks

Statistical analysis of capacitive-filtration properties (CFP) of industrial reservoir rocks and lithological characteristics that varies with depth led to the discovery of regularity of the three main parameters' correlation for the calculation of reserves of hydrocarbons, i.e., coefficients of porosity, permeability and residual fluid saturation. The data on reservoir properties collected on deposits of Oil and Gas Industry of Kazakhstan, America, Central Asia, meeting the requirements of different types of pore spaces and forms of productive layer.

Diagenesis of sedimentary rocks changes the structure of the pore space and within the formation of hydrocarbon deposits reservoir properties are no longer dependent on lithological and petrographic characteristics, however, affect the choice of influence methods on the inflow and the formation of crystalline hydrates in layer conditions.

The nomogram-pallet of CFP's correlation is the base of collectors' classification, and on the periphery of its lines beyond pore conditions (filtering) of fluids moving: gutter, pipe, an enclosed tank and outer space

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which is justified by the formula of reservoir properties ($K = m/ \alpha$).

Commercial discoveries of new oil and gas deposits give confidence to transit from the quantity of laboratory studies of reservoir rocks to the quality of access to concrete evidence of natural law of collectors as part of the space properties in which there is the movement of fluids with different rheological properties. This observation is noted at the level of the structure of the pore space formed by granular material, or by the creation of fracture capillaries under the stress conditions, either by dilution of the mineral matrix by water streams with the formation of cavities to the size of caves with the utmost depth of development that depends on the rock strength. The main difficulty lies in the formalization of the correlation between the three parameters characterizing the structure of the pore space: the coefficients of porosity, permeability and residual (stability) fluid saturation. The coefficients were statistically processed by mathematical methods [1] as the analysis of capacitive-filtration properties (CFP) proceeds.

Most of the core of collectors of the carbonate accumulation of mineral skeleton is from lime-dolomitic and sand composition. Limestone is often fine-grained pelitomorphic with a matrix porosity of 2-5%, permeability less than 1mD and along fractures, respectively, to 2% and more than 15 mD. Among the organic limestone, including fossil dropping, porosity reaches up to 8% and permeability — of about 2 mD. Among the fractures cavernosity is developed to depths of up to 2500 m where according to well testing permeability reaches 0.5 mD. The fine-grained dolomites are industrial collector up to 15% in the presence of fractures where the permeability is within 25-90 mD, even in the case of performing fractures by calcite. Coarse-grained dolomites are rarely being collector except fractured-cavernous ones 2.5% after recrystallization its permeability is up to 1.5 D (Northern Urals - + Ordovician Silurian and the southern Caspian Sea region - carbon + v.devon). Thus, the Dolomites are not much different from the limestone.

Clay minerals, mostly kaolinite and montmorillonite, strongly affect the CFP increasing the residual water saturation. At shallow depths from the surface of sediment they engendered life on Earth but on further immersion crystallization intensity increases clay turning them into a fluid trap. However, at a depth of 4 km loss of water leads to formation of argillites which are able to acquire a fracturing with industrial CFP (West Siberia - Bazhenov Formation and Midcontinent - Mississippi). The collector is similar in properties to fracturing ones with minimal porosity of less than 2% and permeability of more than 1.5 D [2]. Sealing generates abnormal high pore pressure (AHPP) from small to large deposits without water drive. Often dolomitization of argillites and sandstones increases the risk of accidental release during drilling because deposit is hydrodynamically closed.

The next one of the main types of collectors is granular one which deserves great deal of attention. Even a modest orientation of the depth of the sediment bedding distinguishes three steps granular collector changing: a) up to 2500 m of primary dipping of sedimentary particulate material where the genesis of the formation of deposits with conservation of intergranular space independently on mineral collector composition; b) at depths of up to 4500 m processes of transition from diagenesis to katagenesis are dominated to form a primary fracture along which solution of salt-water is still actively circulating. Now salt can perform granular pores; c) fractures predominate deeper increasing permeability and decreasing the residual water to 0.2 but the matrixes are more than 0.9 with a porosity up to 5%. Fractures are almost entirely oil-saturated within the deposit and out of the contour all pores are sealed what generates AHPP. When hydrothermal vent entrances from the depth of the crystalline basement, reservoir rocks are ore-bearing, for example, Zhezkazgan-Balkhash Copperbelt in the area of the deep Earth's crust split.

The reasons for changing of CFP of granular collectors of oil and gas and the presence of the pore space at extreme depths depending on the mineral composition of sedimentary rocks are justified. So, for quartz sands an industrial porosity, based on reservoir pressure, experimentally reaches depths of up to 21 km on the platforms. In active tectonic conditions this depth is decreased to 16 km. Organogenic limestone can have productive porosity of up to 14km due to the low elasticity of grains and crystals of calcite and dolomite [1]. At these depths lithogeneous process of mineral skeleton is since the formation of deposits of hydrocarbons and collectors retain CFP almost to the depth of 16 km what is due to lack of migration routes of aquifer water-brine.

3. Statistical analysis

Statistical analysis of the laboratory data of collectors allows to define the "slip" of water saturation depending on porosity, and the range of change — of permeability in the direction of growth of residual water related with the fine capillaries- sorbents. It is a measure for all collectors with hydrophilic properties and hydrophoby can not be genetically in sedimentary rocks. For carbonate rocks the residual water saturation is well correlated with the porosity and permeability what is comparable with terrigenous collector. These measures do not graphically pick out collectors by mineral composition or structure of the pore space [3]. Dependencies of three parameters of collector with intergranular porosity are the same in the Devonian, Carboniferous and Permian where fracture gives the deviation by permeability. Directions of CFP changes depending on the residual water saturation (a) are shown on the primary pallet where samples with readings in range of 0.2 < and > 0.8 are screened [2]. To simplify constructions and derivation of dependencies of three parameters (K — permeability, m — porosity and α) nomogram graph is plotted (Fig. 1) where two main axes in a logarithmic scale are for visual proof of the Law of collectors — "If two parameters of collector are the same then the third parameter will be the same". The sorption properties of water and hydrocarbons, quantity in layers on the mineral skeleton to layer of moving fluids, which space decreases with increasing of clay crystals, are taken into account [4].

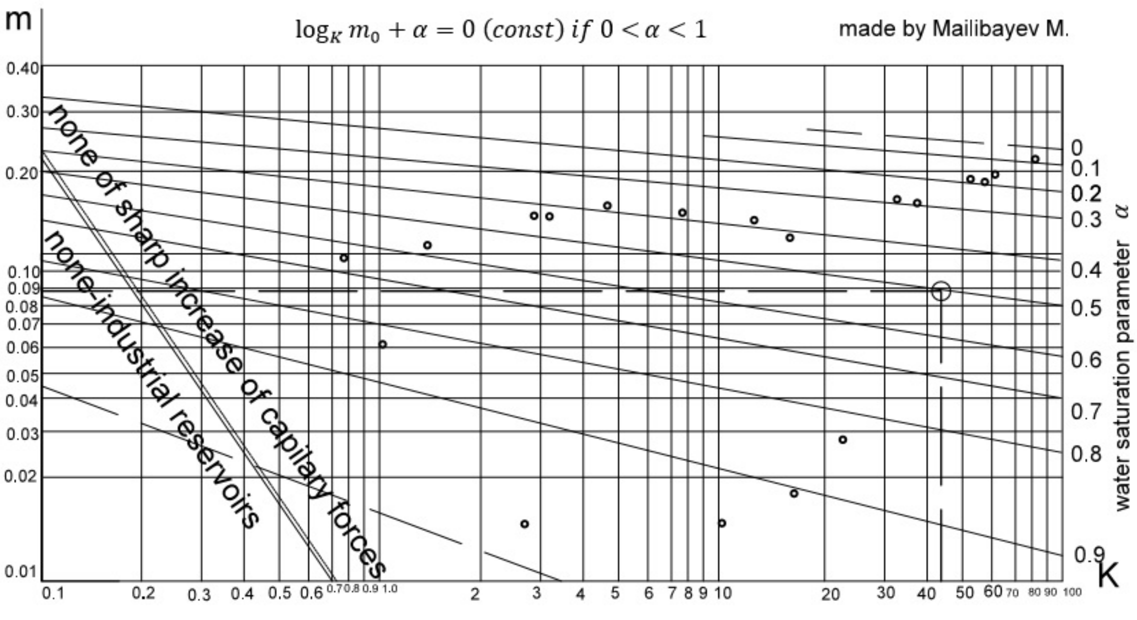

Fig. 1 Three parameters' nomogram graph (K: permeability, m: porosity, α: water saturation).

Therefore, in nature there is no a skeleton with phobic mineral properties viewing to the genetic root of terms of sedimentary rocks accumulation [1].

4. The Main Formula

The study of the structure of the pore space under the petrographic and electron microscopes allowed to establish the degree of secondary changes in the epigenetic and katagenesis processes by the type of cementation of grains and the implementation of macro- to micro-sizes. Cyclicality of pore execution and leaching the mineral skeletons under the influence of tectonic and lithostatic conditions is clearly reflected at CFP just within the maximum saturation of the collector by water. So first of all data of analysis of residual water saturation were sorted what affects the determination of the industrial layer. For polymictic and carbonate collectors properties of the structure of the pore space are comparable, i.e., mineral composition does not affect the CFP which is the starting point of the proof of the Law of Collectors. At extreme depths micropores of sediment rocks are stored. Formalization of three parameters of collector (m, K, α) was obtained by virtue of a study of 17,000 tests (see Table 1), what allowed to determine the main formula on which false laboratory tests can be rejected and the results of studies of the hole on the inflow can be confirmed.

Table 1 Formalization of three parameters of collector.

m	K	α of water	Correlation
0.300	0,15	0.2	0.205276628
0.270	0,6	0.2	0.243777722
0.235	3	0.2	0.292746771
0.214	10	0.2	0.339167143
0.190	40	0.2	0.397343030
0.178	90	0.2	0.437792688
0.256	0.2	0.3	0.157960668
0.224	0.7	0.3	0.201269251
0.190	4	0.3	0.287986147
0.166	20	0.3	0.407771704
0.152	40	0.3	0.459686325
0.145	80	0.3	0.539877215
0.220	0.2	0.4	0.115567223
0.191	0.7	0.4	0.165604671
0.155	40	0.4	0.269870675
0.131	20	0.4	0.434193475
0.117	40	0.4	0.511693450
0.120	80	0.4	0.692495955

m	K	α of water	Correlation
0.152	0.7	0.5	0.127172324
0.123	4	0.5	0.246000000
0.098	20	0.5	0.438269323
0.089	40	0.5	0.562885424
0.081	80	0.5	0.724486025
0.126	0.7	0.6	0.101725391
0.093	4	0.6	0.213657893
0.072	20	0.6	0.434460695
0.065	10	0.6	0.594496567
0.059	80	0.6	0.817910916
0.071	4	0.7	0.187370123
0.054	20	0.7	0.439657774
0.046	40	0.7	0.608414878
0.041	80	0.7	0.880941051
0.049	4	0.8	0.148540223
0.035	20	0.8	0.384496190
0.030	40	0.8	0.573811500
0.026	80	0.8	0.865855336

Properties features of reservoir rocks are identified in three directions of $m = k\alpha^{\varepsilon}$ — unique dependencies:

- At the same porosity of samples with increasing of permeability residual water saturation is naturally decreasing but not in direct proportion;
- At the same permeability with increasing porosity residual water saturation is also decreasing;
- At the same residual water saturation with porosity increasing permeability is decreasing or with permeability increasing porosity is decreasing, what are the signs of fractures.

In connection with the listed behavior of reservoir rocks observed regularity goes beyond the usual properties of rocks of water-saturated industrial rocks and beyond water oil seals that have a diffusion permeability which can be traced on palette.

At the base of the reticulation in the lower left corner there are the most dense rocks (materials) practically having no signs of porosity and permeability in which in the presence of nanopores there are fixed sealed water or other liquids. Only the diffusion migration of water molecules and light hydrocarbons is possible.

In the lower right corner in the reservoir rocks fracturing, on which maximum permeability values are created without matrix porosity and very low residual water, is developed and it fully meets the properties of pipeline in dense depths where non-industrial reserves of mineral fluids can be located

In the upper right space of the reticulation properties of the best reservoir are placed, and in the case of the porosity increasing to close to 1.0 value we get space where permeability is unlimited and stationary liquid is absent.

In the limit in the upper left corner of the reticulation and to the left and up to m = > 1.0 logically a unique container with a hole, which it was filled through, was formed, but the permeability, i.e., through liquid penetration, is absent. That is characteristics of identified in space "black holes".

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