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Lab rock core studies of the Ufimian horizon as a prior step to displacement experiments with steam

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Abstract. The author in this paper determined the coefficient of porosity from well log data and carried on a study of core samples using X-ray microtomography and traditional methods. A method was elaborated and later tested for measurement of porosity of samples taken from the production interval of shallow super viscous oil deposits of the Tatarstan's Republic. Also determination of mineralogical composition and characteristics of the reservoir rock for application to future steam flooding experiments. On the basis of the data obtained, was concluded which of the methods gives the most reliable information on this of the reservoir rock under study.

1. Introduction

Definition of reservoir properties and bitumen saturation of productive rocks is one of the minimum input data to enable assessing reserves and planning methods for extracting bitumen. The source of information may be from core studies or from geophysical surveys. However, in the case of bitumen-saturated loose sands of the Tatarstan Republic, the question of estimates of reservoir rock properties, both from core studies and geophysical surveys, acquires significant importance.

The purpose of the work is to study the properties of the terrigenous reservoir rock of the Ufimian horizon of the super-viscous oil field of the Republic of Tatarstan, in order to clarify the parameters of the bulk model when performing steam flooding experiments. The task comprised the determination and comparison of the coefficient of porosity of weakly cemented – unconsolidated sands, using different methods. Furthermore, to develop and test a method for the determination of porosity in unconsolidated samples. The determination of mineralogical composition and characteristics of the reservoir for application of steam flooding experiments and analysis of the results obtained.

2. Methodology

Determining weakly cemented – unconsolidated sands' parameters of the Nizhnoye-Karamalskoye deposit is of considerable challenge in laboratory practice. This fact is due to the core sampling actual practices which modify the original natural structure of the rock and adding some difficulty to the direct measurement of reservoir rock properties. Hence the need to apply fundamentally different methodological approaches to the study of these rocks when special sampling methods are not used.

The main methodological issues of laboratory analysis of weakly cemented rocks – unconsolidated sands were worked out in collaboration with TatNIPIneft and Kazan State University, which resulted in a Standard of the Company for the analysis of uncemented and weakly cemented rocks in laboratory, introduced into Tatneft in 1996. Due to the fact that bitumen is not mobile, meaning no drilling mud filtration and while performing downhole core sampling, bitumen from the core is not displaced by the drilling mud, therefore with some modification of the technique in this case, gives the possibility to get advantage of this feature and obtain additional information about the reservoir. The developed volumetric method for measuring the porosity of uncemented samples made it possible to determine the clay content, and to conduct a granulometric analysis and X-ray phase analysis.

Nizhnoye-Karamalskoye deposit of super-viscous oils of the Cheremshanskoye field is spatially confined to a sedimentation trap, formed as a result of a local increase in the thickness of the sand pack of the Sheshminsky horizon. The deposit is confined to the crest of reservoir and crest position trap parts, catches and refers to the type of Layer-uplifted deposit. Oil sands have high reservoir properties.

2.1 Porosity measurement methods

2.1.1 Porosity measurement based on gamma-gamma density data

Gamma-gamma density log has a high geological efficiency and is applied for the determination of bulk density, porosity, lithotype definition, characterization of geological bodies with anomalously low bulk density. The density gamma-gamma log method is based on measuring the intensity of artificial gamma radiation scattered by rock-forming elements in the process of irradiating them with a stream of gamma



rays. From the (1) it follows that to determine KP according to the gamma-gamma density logging data, it is necessary to know the values δ_f and δ_m

$$Kp = \frac{\delta_m - \delta}{(\delta_m - \delta_f)} \quad (1)$$

Where:

Kp: Porosity coefficient (dimensionless);

δ is the bulk density of the rock (g/cc);

δ_m is the density of the matrix (g/cc);

δ_f is the density of the fluid filling the pore space (g/cc).

The density of the matrix = 2.7 g/cc, the density of the reservoir fluid = the density of bitumen 0.98 g/cc.

2.1.2. Porosity measurement with x-ray computed tomography (sandstone)

Core measurements were performed using a 2D inspection of Phoenix v|tome|x s240 in the X-ray computed tomography laboratory of the Institute of Geology and Oil and Gas Technologies of Kazan (Volga Region) Federal University [1] (Fig. 1). The method of non-destructive study of the internal structure of an object is based on measuring the attenuation of X-rays by different parts of the object, with different density, composition, and thickness. For the formation of three-dimensional images of the internal structure of the object, complex computer processing of data sets over a set of its 2D shadow projections is used.



Fig. 1. Micro / nanofocal system for computed tomography Phoenix v|tome|x s240

2.1.3. Study of measurement with traditional method (open porosity with sandstone)

Method for determination of the coefficient of open porosity by liquid saturation. Additionally, bulk density, bulk bitumen saturation. The technological sequence of operations are as follows:

1. The saturation of the rock samples with the fluid (kerosene or a simulated formation water) using the capillary imbibition. [2] Fig.2
2. Weighing saturated sample in the saturating fluid and in air
3. According to the results of weighing are carried out calculations as:
 - the ratio of open porosity,
 - bulk density
 - bulk bitumen saturation
4. Drying samples at 105 ° C for 40 h

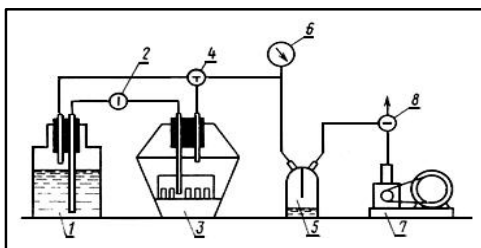


Fig.2 Device for samples' saturation. 1-vessel for saturating fluid; 2- shut-off valve; 3- vessel for saturation of samples; 4- three-way crane; 5-trap for preventing liquid from entering the vacuum pump; 6 - pressure gauge; 7-vacuum pump; 8- shut-off valve of the vacuum pump and filling the system with atmospheric air.

2.1.4. Study of porosity measurement with volumetric method (unconsolidated sand)

Determination of the parameters of the unconsolidated sands of the Nizhnoye-Karamalskoye deposit is of considerable difficulty in laboratory practice. The developed volumetric method for studying porosity allowed to determine the parameters of weakly cemented rocks and unconsolidated sands that are most commonly found in core samples from the Ufimian and Kazanian horizon

The studied samples are weakly cemented – unconsolidated, intensively bitumen-saturated unconsolidated sands. It is relatively weakly compressed by the pressure of the overlying rocks due to the shallowness of the reservoir formation. The highly-viscous oil represents the cementing material. In the volumetric method of determining porosity, we assume that bitumen occupies the entire porous volume of the sample. Thus, immersing the sample in a liquid (benzene), we can determine the total volume of the sample. Cold extraction of bitumen was carried out using two solvents: benzene and chloroform. For the first stage of extraction of bitumen from the sample, benzene was used. The completion of the extraction was determined visually, when the extraction liquid (benzene) showed itself transparent. Chloroform was used to dissolve the residual hydrocarbons, and the end of extraction was also determined visually. After the complete removal of bitumen from the sample immersed in benzene, was determined the volume of bitumen extracted. The difference between the total volume of the sample and the volume of the extracted sample is equal to the pore volume (we assume that bitumen occupies the entire porous volume of the sample). Porosity is defined by:

$$Poro = \frac{V_p}{V_s} \quad (2)$$

Where:

Poro - Porosity (dimensionless);

V_p - pore volume (ml);

V_s - sample volume (ml)



Fig.3 Bitumen saturated, unconsolidated sand of the Ufimian horizon sample. Determination of the sample volume before extraction by immersion in benzene. Determination of the sample volume after extraction by immersion in benzene.

2.2. Determination of the mineralogical composition.

The bitumen extracted samples and remaining sediments on filter paper after the volumetric method for determination of porosity and river sand for bulk model were sent to the laboratory of X-ray phase analysis for determination of its mineralogical composition. X-ray phase analysis identifies the various phases in the mixture based on the analysis of the diffraction pattern given by the sample under study. The determination of a substance in a mixture is carried out by the set of its interplanar distances and relative intensities of the corresponding lines on the radiograph. The sand pack of the Ufimian horizon is composed of polymictic sands representing gray, light gray rocks.

2.3. Granulometrical features of unconsolidated sands.

The granulometric composition of rocks is the quantitative content of particles of various sizes in the rocks. The granulometry characterizes the degree of dispersion of mineral particles composing the rock. Many other reservoir properties of the porous medium depend on the degree of dispersion of minerals:

porosity, permeability, specific surface area, residual water saturation, oil saturation, capillary forces, and others. After cold extraction the samples passed through sieve and determined granulometric composition of rock [3].

2.4. Clay index of unconsolidated sands.

The clay index is a property of rocks to contain particles with a diameter less than 0.01 mm. Clay particles are fragments of clay minerals + impurities. The properties of rocks contain a number of clay particles that occupy a space between larger grains. It is called dispersed system in contrast to the actual thin interlayering system of the rock. On the filter paper after cold extraction and during the determination of porosity by the volumetric method, a remaining sediment was obtained and was sent to X-ray phase analysis. The sediment was confirmed to be a clay. The clay content of sedimentary rocks is characterized by the content in the rock matrix of a rock with an effective diameter of less than 0,01 mm. Clay content is usually set according to the granulometric composition of rocks and is calculated by (3):

$$C = \frac{M_f}{M_m} \quad (3)$$

Where:

C – Clay index (dimensionless);

M_f - mass fraction with a diameter of <0,01 mm (g);

M_m - mass of the sample (g)

3. Results and discussions.

Studies of bituminous core rocks require a different treatment from the standard approach. The large number of steps of the process along with the number of samples' weighting and corrections for losses in weights lead to a highly time consuming duty in comparison with studies of core samples of conventional reservoirs. The measurement of porosity with the different methods used in this study (Table 1), for weakly cemented sandstones and unconsolidated sands show an average porosity of 30%.

№ Well	X-ray computed tomography Porosity %	Traditional method Porosity %	GGKp) Porosity %
Study of porosity of consolidated sandstone			
149/1	30,11	29,9	29,8
149/2	30,96	28,7	27,8
153/1	27,92	-	25-30
153/2	25,62	-	26
155	32,97	-	31,5
162	26,08	29,8 -33,5	31,5
164	29,9	29,8	29,8
Study of porosity of unconsolidated sand			
		Volumetric method, Porosity %	
150/1	-	30	30
150/2	-	29	30
156	-	29	29
160	37,27%	25	27

Table 1. Results of porosity measurements of core samples of the Ufimian horizon using different methods.

The sand pack of the Ufimian horizon is composed of polymictic sands (Fig.4a) representing gray, light gray rocks. For bulk model we will use common river sand which was also analyzed and showed a more inert nature (Fig.4b). These rocks consist mainly of grains of quartz rounded to different degrees.

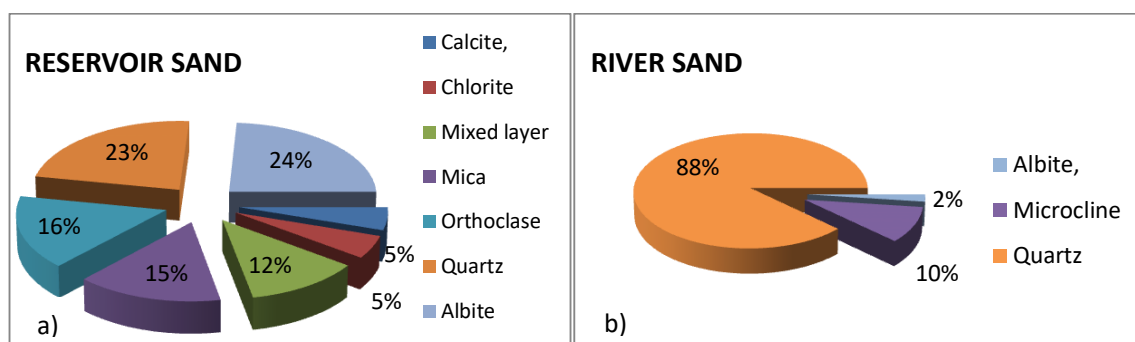


Fig.4 X-ray phase analysis results for reservoir sand and common river sand

The Nizhne-Karmalskoye deposit of the Cheremshanskoye field is represented by the Sheshminsky horizon (Fig. 5), consisting of a lower sand-clay pack and the upper sandstone pack. The overlaying rock, which lies on top of the sand pack is composed of clay, dark gray, with a bluish tinge and is a good cap rock (Lingula clay). X-ray phase analysis results show, from Lingula clays, clays from the pay zone, clays from the lower sandy clay package have the same clay components. The granulometric composition of the mixture of various fractions up to 0.5mm of quartz sand (Table 2). On the filter paper after cold extraction and during the determination of porosity by the volumetric method, a remaining sediment was obtained and was sent to X-ray phase analysis. The sediment was confirmed to be a clay. The clay index of the studied samples was determined (Fig.6). From (4): The clay content is equal to 6%. However, among all the samples analyzed it was obtained and average value of 4% (by weight) (table 3).

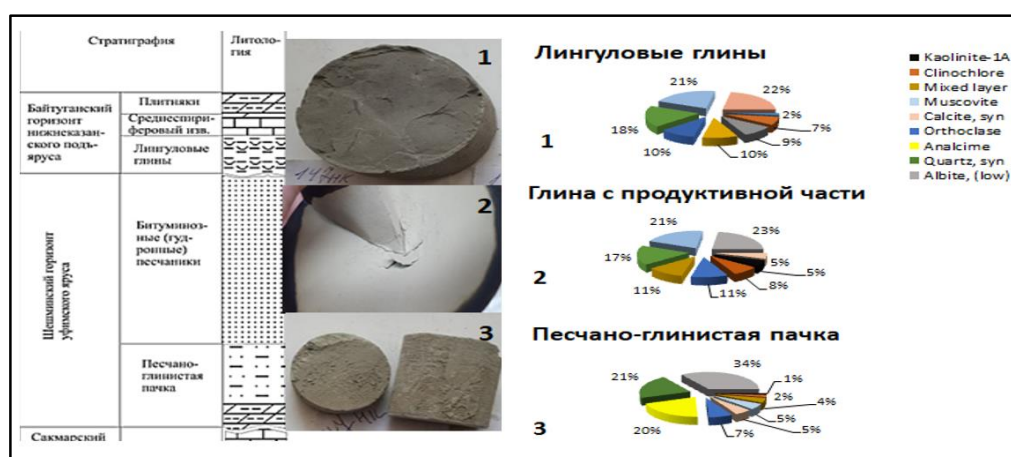


Fig.5 Average well section of the cap rock and pay zone samples of the Ufimian horizon for research in X-ray phase analysis (1 - Lingula clays, 2 - clays from the sand pack pay zone, 3 - clays from a sandy clay package)

Cell size mm	Sand from reservoir, g	River sand, g
1	-	0,85
0.8	-	0,683
0.63	-	1,183
0.5	-	2,007
0.315	0,356	17,78
0.16	7,405	47,205
0.08	2,611	6,345
0.063	0,278	0,186
0.032	0,419	0,076
0.025	0,051	0,004
Sample mass without losses	11,28	76,916

Table 2. Granulometric composition of samples of the Ufimian horizon under study.

$$C = \frac{2.601}{45.028} = 6\% \quad (4)$$



Fig.6 Sample weight without sediment (a) and with sediment (b)

№ Well	Clay content, %
149/1	4
149/2	4
153/1	5
153/2	6
155	3
162	4
164	4
150/1	4
150/2	3
156	5
160	4

Table.3 Results of measurements of Clay content in studied samples

Conclusions

The studies run have shown that the developed volumetric method for measuring porosity can be technologically simple, and is recommended for determinations of porosity of weakly cemented sandstones and unconsolidated sands. It expands the capabilities of their research, allowing measurements on wet and dry core samples, which cannot be studied by the traditional method, when no special downhole sampling methods are used. As a result of the obtained values the reservoir sands and sandstones are characterized by good reservoir properties and have an average porosity of 30%, a mixture of various fractions up to 0.5mm of quartz sand. X-ray phase clay analysis results show that for a bulk model can be used clay from a sandy clay package with average value clay content of 4% (by weight). According to the results obtained, they will be used for estimations of pore volumes of future displacement experiments with steam.

References

- [1] <https://kpfu.ru/laboratoriya-rkt-70706.html>
- [2] GOST 26450.1-85 "Method for determination of open porosity by fluid saturation"
- [3] GOST 12536 -2014 "Soils. Methods of laboratory granulometric (grain-size) and microaggregate distribution"