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EFFECT OF THE TYPE OF PRETREATMENT ON THE UNIAXIAL COMPRESSIVE STRENGTH OF A ROCK CORE SAMPLE

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Uniaxial compressive strength measurements were made on different artificial rock core samples with different mineral compositions, particle size distributions, permeability, void ratio, and other parameters and subjected to different types of pretreatment. Poisson's ratio and the elastic modulus of the samples were measured. It was established that the best method for preparing the sample for the measurements is to saturate with water under vacuum and then heat the oil and gas under pressure, simulating formation pressure.
Key words: *core, uniaxial compression, Poisson's ratio, elastic modulus (Young's modulus).*

Currently, during exploration of oil and gas deposits, when simulating formation conditions or studying the effect of evolution of formation fluids on rock strength, the rocks need to be properly pre-treated before measuring uniaxial compressive rock strength. Pretreatment of the sample can involve desiccation [1-7], desiccation by heating, and soaking with a special fluid (cavitation fluid). Desiccation under normal conditions (natural desiccation) presumes air-drying at ambient temperature; desiccation by heating (hot desiccation) involves heating to formation temperature [8-10] and drying by a stream of air with temperature 100°C [11-12] and above 190°C [13-14]. Soaking with cavitation fluid involves saturation with the fluid under normal conditions (non-vacuum saturation) [10, 15-24], saturation under vacuum (vacuum saturation)

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Table 1

No.	Particle size, mm	Accumulation, %	No.	Particle size, mm	Accumulation, %
1	0.7071	0	11	0.1250	96.05
2	0.5946	4.03	12	0.1051	97.86
3	0.5000	11.99	13	0.0884	98.55
4	0.4204	21.94	14	0.0743	99.25
5	0.3536	47.49	15	0.0625	99.58
6	0.2973	63.57	16	0.0526	99.83
7	0.2500	74.44	17	0.0442	99.93
8	0.2102	82.98	18	0.0372	99.96
9	0.1768	88.58	19	0.0313	100.00
10	0.1487	93.45	20	0.0156	100.00

Table 2

No	Treatment	Description	Total number of rock core samples
1	Natural desiccation	Direct exposure to air after coring (2 groups of samples)	2
2	Water soaking	1. Coring, desiccation, and non-vacuum water soaking (7 groups) 2. Coring, desiccation, and vacuum water soaking (7 groups) 3. Coring, desiccation, vacuum water soaking, and creation of pore pressure 28 MPa (7 groups)	21
3	Oil-driving	Coring, desiccation, vacuum water soaking, and complete displacement of water by oil (2 groups)	2
4	Gas-driving	Coring, desiccation, vacuum water soaking, and complete displacement of water by nitrogen (2 groups)	2

[12, 25-32], and saturation under pressure (pressure saturation) [33]. The saturation fluid is usually pure water, formation water, drilling fluid, acid, solutions of base, salt, and hydrocarbon, i.e., fluids which are typically used to study the strength characteristics of rock. For measuring the permeability of rock samples, before pretreatment for the studies, they were washed to remove oil (oil washing) [34, 35] followed by oil saturation to form the initial oil and water saturation state. In order to measure gas permeability, after vacuum water saturation we need to saturate with gas (gas-drive).

Today there is no single standard for sample pretreatment for void factor measurement, but many methods are available. The large number of rock strength parameters leads to confusion in the data for predicting well-wall stability and sanding, and complicates the process of taking necessary measures. Currently studies are often conducted on natural non-homogeneous rock cores. Artificial rock core samples can be made with prespecified mineral composition and particle size distribution and permeability. The samples having identical properties lets us study the effect of the type of treatment on the rock strength.

The prepared samples of the specified mineral composition have void factor 18% and permeability $192 \cdot 10^{-3}$ μm^2. The studies were conducted at a pressure of 28 MPa and a temperature of 105°C. The particle size distribution of the samples is given in Table 1; the constituent composition is given below (wt.%):

Quartz 75
Feldspar 5
Plagioclase 2
Dolomite 5
Siderite 2
Clay, including:: 13
    Illite 41
    Kaolin 27
    Chlorite 10
Illite/smectite ratio 20

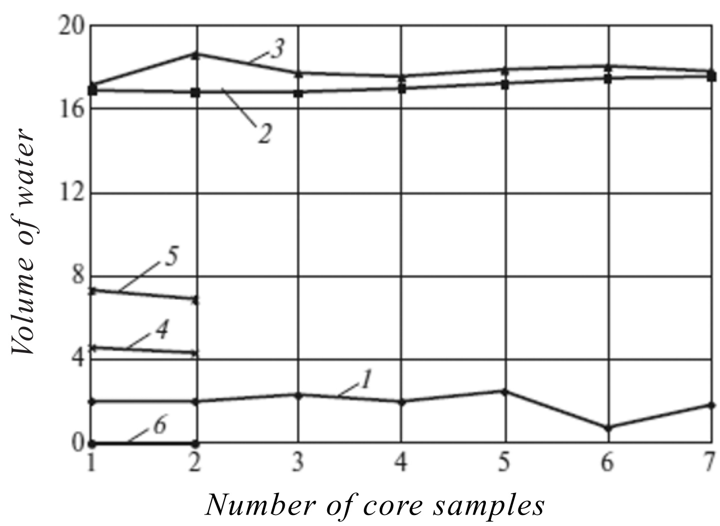

Fig. 1 Water saturation according to type of core sample treatment: 1) non-vacuum water soaking; 2) vacuum water soaking; 3) vacuum pressure water soaking; 4) oil-driving; 5) gas-driving; 6) natural desiccation.

A powder (core sand) was prepared according to the data presented above, and this was then pressed to produce the core. The special rock briquetting press makes it possible to make up to 40 rock core samples with identical properties in a single operation that meet the specified requirements. Addition of water was avoided in making the cores and so water did not have any effect on the rock strength, improving the reliability of the measurements.

The uniaxial compressive strength, the elastic modulus, and Poisson's ratio were measured for the samples after different types of treatment (Table 2).

Individual rock core samples (with the same physical properties) were pressed based on the actual stratigraphy and data on particle size and the physical parameters. The uniaxial compressive strength tests were conducted on 7 groups of samples under water-soaking conditions in order to assess the effect of the timing and the type of treatment on the strength parameters of the samples. Since the treatment time for

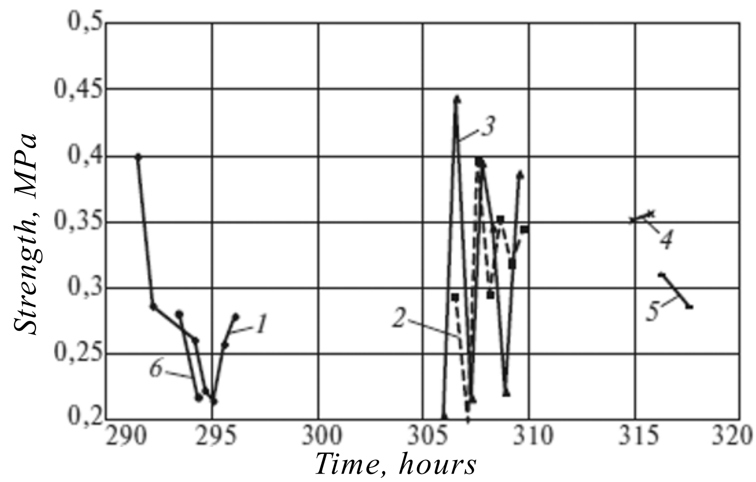

Fig. 2 Change in uniaxial compressive strength vs. time according to type of core sample treatment: *1*) non-vacuum water soaking; *2*) vacuum water soaking; *3*) vacuum pressure water soaking; *4*) oil-driving; *5*) gas-driving; *6*) natural desiccation.

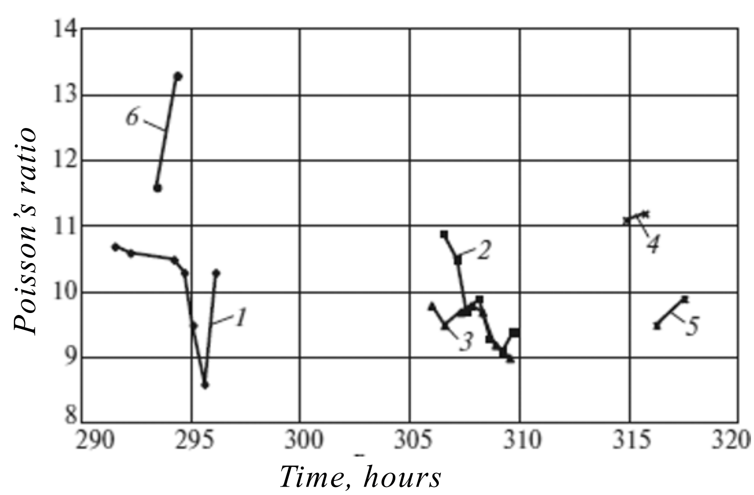

Fig. 3 Change in Poisson's ratio vs. time according to type of core sample treatment: *1*) non-vacuum water soaking; *2*) vacuum water soaking; *3*) vacuum pressure water soaking; *4*) oil-driving; *5*) gas-driving; *6*) natural desiccation.

desiccation, oil-driving or gas-driving has little effect on strength characteristics, only two tests were conducted in duplicate to reduce the error.

We chose formation water as the liquid in order to assure reliable study results. For accuracy in the study, the desiccation temperature of the sample was taken as equal to the temperature under formation conditions, 105°C. The test with specially prepared purified oil (white oil) with viscosity 28 mPa·s was conducted at vacuum gauge pressure of 0.1 MPa.

The permeability and void factor of the samples were equal to respectively $180 \cdot 10^{-3}$ - $220 \cdot 10^{-3}$ μm^2 and 16.4%-9.6%.

Fig. 1 shows the volume of absorbed water in order of decrease when carrying out different treatments: vacuum pressure water soaking (creating pore pressure) > vacuum water soaking > gas-driving > oil-driving > non-vacuum water soaking > natural desiccation. The volume of absorbed water in the gas-driving experiment is less than in the oil-driving experiment, due to water channeling which arises for a gas/water flow rate ratio >1 and involves preferential seepage of gas through high-permeability channels. For oil-driving, the corresponding ratio is less than 1, and consequently the water is successfully driven out from the rock core sample. Different water contents in the sample have an effect on its strength, and generally the strength of the rock core sample decreases with an increase in water content.

As we see from Fig. 2, as soaking time increases, the water sensitivity of the core sample increases, and consequently in most cases the strength decreases. The highest water sorption (in the vacuum pressure water soaking experiment) corresponds to the lowest uniaxial compressive strength. Water sorption in the vacuum water soaking experiment also is high, while the strength is only slightly lower than in the non-vacuum water soaking experiment. After non-vacuum water soaking, generally the strength is higher than in the gas-driving experiment, since in the second case the water sorption is higher despite the fact that some of the water was displaced. Since the oil during oil-driving reduces the water sensitivity (hydrophilicity) of the rock core, the strength in this case has the maximum value except for the natural desiccation experiment. The core samples are therefore ranked according to decrease in uniaxial compressive strength from high to low as: natural desiccation, oil-driving, non-vacuum water soaking, gas-driving, vacuum water soaking, vacuum pressure water soaking.

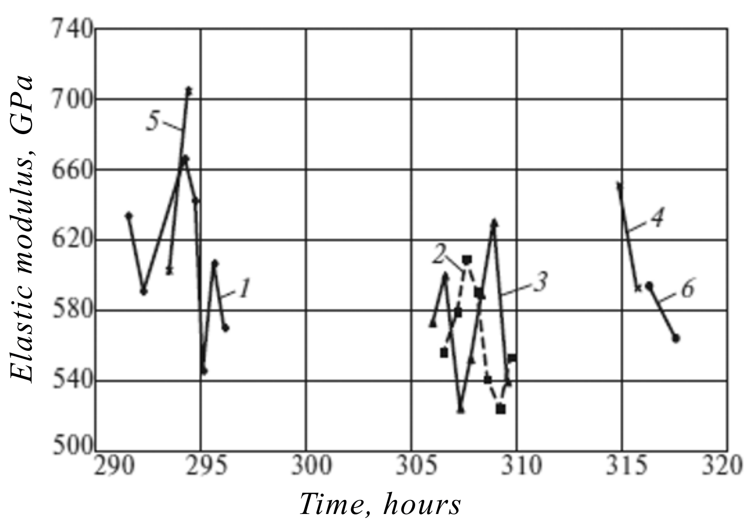

Fig. 4 Change in elastic modulus vs. time according to type of core sample treatment: *1*) non-vacuum water soaking; *2*) vacuum water soaking; *3*) vacuum pressure water soaking; *4*) oil-driving; *5*) gas-driving; *6*) natural desiccation.

As we see in Fig. 3, the core sample after the natural desiccation experiment has the lowest Poisson's ratio. We obtained about the same values of Poisson's ratio in the vacuum water soaking experiment and the vacuum pressure water soaking experiment. In the gas-driving experiment, Poisson's ratio is often higher than in non-vacuum water soaking experiments, in connection with the high water sorption, the high water sensitivity (hydrophilicity) and plasticity in the first case. For the oil-driving case, Poisson's ratio is high due to the fact that seepage of oil occurs between rock particles.

Based on the graphs presented in Fig. 4, we can see that the highest value of the elastic modulus corresponds to the core sample from the natural desiccation experiment. On the whole, the elastic modulus for non-vacuum water soaking and in the oil-driving experiment is higher than in the vacuum water soaking case and in the vacuum pressure water soaking case.

The last two experiments give approximately the same value for the elastic modulus. Table 3 presents the average values for all the test parameters for core samples subjected to a particular treatment method.

From the average values of the strength parameters given in Table 5, it follows that the core sample subjected to natural desiccation, having the highest uniaxial compressive strength and elastic modulus, has the lowest Poisson's ratio due to hydrophobicity. In the oil-driving case, the hydrophilicity of the sample decreases due to wetting of the rock by oil, and consequently the strength and elastic modulus are lower than in natural desiccation while Poisson's ratio is maximum.

The three water soaking methods and gas-driving affect the hydrophilicity in such a way that the strength and the elastic modulus become lower than for natural desiccation and oil-driving, while Poisson's ratio is higher than in natural desiccation. In connection with the relatively small amount of water entering the rock during non-vacuum water soaking, the strength of such a sample is higher than in vacuum water soaking, vacuum pressure water soaking, and gas-driving experiments. The Poisson's ratio obtained for non-vacuum water soaking is lower than in the first three cases, while the elastic modulus is not very different. Vacuum pressure water soaking enables entry of a large volume of water into the rock, which promotes a decrease in strength and elastic modulus and an increase in Poisson's ratio, compared with the usual vacuum water soaking. Water sorption and accordingly Poisson's ratio in the gas-driving experiment are found to be lower than in vacuum water soaking and vacuum pressure water soaking experiments, but are higher than for non-vacuum water soaking. No other significant differences were found in the strength and elastic modulus.

Table 3

Indices	Value					
	Non-vacuum water soaking	Vacuum water soaking	Vacuum pressure water soaking (creating pore pressure)	Oil-driving	Gas-driving	Natural desiccation
Elastic modulus, GPa	0.57	0.61	0.57	0.62	0.58	0.65
Poisson's ratio	0.28	0.31	0.32	0.36	0.30	0.25
Uniaxial compressive strength, MPa	10.1	9.8	9.5	11.2	9.7	12.6

Since in vacuum water soaking and vacuum pressure water soaking experiments, a sufficient volume of formation water penetrates into the rock, we can observe the impact of water on the strength and its time variation. Differences in the strength tests may be due to differences in the fabricated core samples, but the small differences in this study confirm the homogeneity of the fabricated core samples.

From the change in strength and other test parameters of the core sample with different treatments, we can directly evaluate the well-wall stability and sanding. Different treatments of the rock core sample were used with the aim of simulating the actual well conditions. The sample under natural desiccation conditions does not correspond to formation conditions; without vacuum water soaking, it is impossible to achieve the natural water distribution due to the presence of air bubbles within the rock. In order to reproduce the formation conditions, the rock core sample at formation temperature is subjected to vacuum soaking, and then oil-driving or gas-driving to displace the liquid. In order to avoid an influence on the strength from high temperature, arising due to vaporization of the formation fluid, it must be injected at formation pressure.

In conclusion, we note that vacuum soaking of the core sample at formation temperature followed by oil-driving to displace the water, and then injection of the formation fluid at formation pressure is the best way to treat the rock core samples.

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