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Original article

Hydrogen influence on transformation of terrigenous reservoir physical and mechanical properties

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Abstract:
The article aims to describe a methodology for studying the dynamic, stress-strain properties and density of core samples before and after exposure to hydrogen. The Stages of sample studies and the instruments used in laboratory experiments are examined on the example of core samples taken from the Bobrikov formations in the Volga-Ural oil-and-gas bearing region. A comparative analysis of dynamic properties, density, Young's modulus and Poisson's ratio was carried out before and after ex-posure to hydrogen. It was discovered that after exposure to this gas, interval transit time of acoustic P-wave and S-wave through the samples decreased by an average of 2.4%; Young's modulus increased by 6.5%, while Poisson's ratio remained virtually unchanged. Besides, the research results demonstrat-ed an increase in sample density by 1.1%. The analysis of correlation dependencies revealed a typical change in interrelation of the parameters of P-wave interval transit time with Young's modulus and S-wave interval transit time after samples exposure to hydrogen. Overall, based upon the results of the studies of density, dynamic properties, and Young's modulus, there is evidence of weakening of the stress-strain properties in the core samples. However, such change does not have a major effect on their absolute values. Analysis of the results collected during laboratory experiments shows that the consid-ered horizon could potentially be the formation for the storage of a methane-hydrogen mixture.

1. Introduction

All over the world, the leading scientists and experts draw attention to the fact that the use of conventional fuels leads to growing emissions of harmful substances into atmosphere and global warming. It is noted that due to the growing of CO_2 emissions, it is necessary to make decisions and implement technologies for carbon dioxide sequestration (Fedoseev and Tcvetkov, 2019; Zhang et al., 2022; Wei et al., 2023). At the same time, the problems associated with the use of hydrogen in various industries as an environmentally friendly energy carrier are being increasingly investigated.

Hydrogen energy application defines new challenges related to the production, storage and transportation of hydrogen. There is an opinion that environmentally friendly methods of hydrogen production are often more energy-intensive (El-Shafie et al., 2019; Li et al., 2020; Litvinenko et al., 2020; Mahdi et al., 2021; Guo et al., 2024). Despite this, the authors recommend us-ing hydrogen production technologies without harmful gas emissions into the atmosphere. When storing this gas, the reservoirs must meet special requirements in order to prevent its leakage, moreover the structures themselves must be made of corrosion-resistant materials (Tarhan Çil, 2021; Agyekum et al., 2022). Similar requirements should be applied to the gas transmission system (Hafsi et al., 2018; Cai et al., 2022). In addition, the authors of the studies focus on the

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Fig. 1. Source core material and samples after drilling out.

possibility of various options for transporting liquefied gas, which also leads to the introduction of additional production capacities for its liquefaction.

One of the possible ways to store hydrogen is to pump it into underground salt caverns (Li et al., 2017; Hematpur et al., 2023; Wan et al., 2023). In this case, the gas is pumped either into already created storage facilities, or new caverns are being washed in the territories of the proposed energy storage. At the same time, salt deposits of the required thickness may not be located in all areas of the possible underground gas storage facilities (UGS).

Alternative hydrogen storage facilities may include aquifers and depleted gas fields or traditional UGS (Pfeiffer et al., 2017; Lur'e, 2021). Hydrogen storage in reservoir rocks requires specialized preliminary calculations that take into account such negative factors as loss of gas volumes due to its greater mobility and diffusion compared to methane. Injection of a methane-hydrogen mixture into reservoir layers entails a number of negative effects that must be studied theoretically and experimentally in advance. In particular, as shown in the following studies (Shadravan and Amani, 2019; Martin, 2020; Trautmann et al., 2020), the metal constructions of wells and different equipment begin to lose their elastic-strength properties due to the effects of material embrittlement under the influence of hydrogen. This phenomena can lead to leaks in the casing strings of UGS wells and, in the worst case, to their crumpling.

It is noted that another drawback of the hydrogen-methane mixture storage in reservoir rocks is the possible chemical interaction of hydrogen with the mineral rock matrix (Yekta et al., 2018; Abramova and Filippova, 2021; Abukova and Abramova, 2021). Experts have demonstrated that hydrogen interacts most actively with minerals containing iron and aluminum, as well as with carbon dioxide and sulfates dissolved in reservoir water. The chemical interaction of gas and minerals can lead to the transformation of the lithological composition of rocks and, above all, intergranular cement in a terrigenous reservoir, which in turn entails variations in filtration-capacitive and physical properties of the reservoir (Popov et al., 2013; Flesch et al., 2018; Heinemann et al., 2021).

Recent studies show that the negative effects of hydrogen storage should include the vital activity of bacteria that live in aquifers and UGS (Ebigbo and Gregory, 2021; Nazina et al., 2021; Abukova et al., 2023). The interaction between bacteria and hydrogen will primarily cause the formation of hydrogen sulfide, which will lead to the occurrence of new chemical reactions that result in chemical erosion of the wells materials and the mineral matrix of the reservoir.

The transformation of the elastic-strength parameters of the reservoir rocks, as well as variations in reservoir pressure, can lead to a complication of the geodynamic situation near such UGS (Kashnikov et al., 2010; Pfeiffer et al., 2016; Shevchuk et al., 2019), which requires additional research in the territories of UGS associated with the observation of the Earth's surface deformations.

Based on the publications analysis, it was concluded that the study of hydrogen storage effect on the physical properties of reservoir rocks has been studied very poorly in case of storage of a methane-hydrogen mixture in depleted gas deposits or aquifers. In connection with the above, this work focuses on the study of variations in the elastic-strength and wave characteristics of the reservoir rock under the influence of hydrogen. The research was carried out on the example of core samples of terrigenous deposits of the Bobrikov horizon of the Volga-Ural oil-and-gas bearing region. The changes in the strength limits, density and elastic characteristics of rocks (Young's modulus, Poisson's ratio) were examined using static and dynamic methods. The Bobrikov formation is a potential hydrogen storage facility due to its high porosity and permeability, as well as due to the existing experience in creating a traditional natural gas storage facility in this formation.

2. Methodology

Core samples for the investigation were taken from the depth of 1,488.4-1,489.8 m from intervals with the best reservoir properties. The Bobrikov horizon in the Volga-Ural oil-and-gas bearing region was chosen for the study, since this geological formation stores gas at the Karashurskoye UGS in the Udmurt Republic (Koshevarov, 2004; Garaishin and Ruban, 2010; Vorobiev et al., 2017). Samples of standard size (length and diameter 3 cm) and 2 to 1 size (length 6 cm, diameter 3 cm) were taken from the source core (Fig. 1). Using standard samples was aimed to study variations in reservoir properties under the influence of hydrogen (Popov et al., 2023) as well as density, dynamic properties and tensile

Table 1. Main Stages of the research program, equipment and determined parameters for each group of 4 samples.

Stage	Content of research Stage	Unit used	Determined parameters
1	Samples are extracted and dried; for all samples bulk density, interval transit time of P and S waves, Young's mod-ulus and Poisson's ratio are determined by the dynamic method.	Uzor-2000	ρ, t_p, t_s, E_{dyn}, v_{dyn}
2	For one longer sample from each group, Young's modu-lus, Poisson's ratio and compressive strength are deter-mined using the static method. For one standard sample from each group, tensile strength is determined.	Press IP-100, strain meter SI-2	E_{stst}, v_{stat}, σ_c, σ_t
3	The remaining one long and one standard sample from each group are placed in a cylinder into which hydrogen is injected afterwards. Samples are kept in the cylinder for 7 days.	Cylinder for injecting hydrogen	-
4	For samples removed from the cylinder, bulk density, interval transit time of P and S waves, Young's modulus and Poisson's ratio are determined by the dynamic method.	Uzor-2000	ρ, t_p, t_s, E_{dyn}, v_{dyn}
5	For samples removed from the cylinder, Young's modulus, Poisson's ratio and compressive strength are determined by the static method for the longer sample. For one standard sample tensile strength is determined.	Press IP-100, strain meter SI-2	E_{stat}, v_{stat}, v_{stat}, σ_c, σ_t

strength. The static method was used for longer samples in order to determine the reservoir properties (RP), the values of Young's modulus, Poisson's ratio and ultimate compressive strength.

Drilled-out samples were extracted and dried, and then groups of 4 samples were formed for the comparative analysis of physical and mechanical properties before and after exposure to hydrogen. Each group consisted of two standard samples and two longer ones. For one standard and one longer sample from each group, stress-strain properties were studied using the static method before exposure to hydrogen, as a result of which the samples were destroyed. Then, the two remaining samples from each group were exposed to hydrogen, and subsequently their stress-strain properties were defined by the static method. In order to examine the physical and mechanical properties of core samples, a special research program shown in Table 1 was developed. The research program was as follows.

Stage 1: At this Stage, the density of core samples was determined by the volumetric method and interval transit time of P (t_p) and S (t_s) waves according to GOST 21153.7-75.

Based on the known wave properties and density of samples, the dynamic elastic characteristics of the rock such as Young's modulus (E_{dyn}) and Poisson's ratio (v_{dyn}) were calculated on the basis of the following dependencies (GOST 21153.7-75):

$$E_{\text{dyn}} = \frac{\rho V_S \left(3V_P^2 - 4V_S^2\right)}{V_P^2 - V_S^2} \tag{1}$$

$$v_{\text{dyn}} = \frac{\frac{V_P^2}{V_S^2} - 2}{\frac{2V_P^2}{V_S^2} - 2} \tag{2}$$

where ρ is the rock density, g/cm^3; V_P and V_S are the velocities of P and S wave, m/s; correspondingly.

Besides, travel velocities of P and S waves are the inverse values of interval transit time of the wave:

$$V_P = \frac{1}{t_p} \tag{3}$$

$$V_S = \frac{1}{t_s} \tag{4}$$

Stage 2: Since the static method of studying stress-strain properties is more reliable than the dynamic one, Young's modulus, Poisson's ratio, compressive and tensile strength were determined by this method for some samples using an IP-100 laboratory test press and digital strain meter SI-2.

Strength properties were determined according to GOST 21153.3-85, GOST 21153.2-84 based on the following dependencies:

$$\sigma_t = \frac{10P}{S} \tag{5}$$

$$\sigma_c = \frac{10F_H P}{S} \tag{6}$$

where σ_t is the tensile strength, MPa; σ_c is the compressive strength, MPa; P is the destructive force, kN; S is the cross-sectional area of the sample, cm^2; F_H is the dimensionless sample height factor determined from GOST 21153.2-84.

Determination of elastic characteristics by the static method was accomplished in accordance with GOST 28985-91, while stress-strain diagrams were plotted for core samples. On the basis of such diagram, the characteristic values of stress and strain were determined using which Young's modulus and Poisson's ratio were calculated from the following relations:

$$E_{\text{stat}} = \frac{\sigma_e - \sigma_b}{\varepsilon'_{1e} - \varepsilon'_{1b}} \tag{7}$$

$$v_{\text{stat}} = \frac{\varepsilon'_{2e} - \varepsilon'_{2b}}{\varepsilon'_{1e} - \varepsilon'_{1b}} \tag{8}$$

where E_{stat} is static Young's modulus, GPa; v_{stat} is static Poisson's ratio, f.u.; σ_e, σ_b are the stresses at the end and beginning of a given range during destressing, MPa; ε'_{1e}, ε'_{1b} are the relative longitudinal deformations of the sample at the end and beginning of a given range during destressing; ε'_{2e},

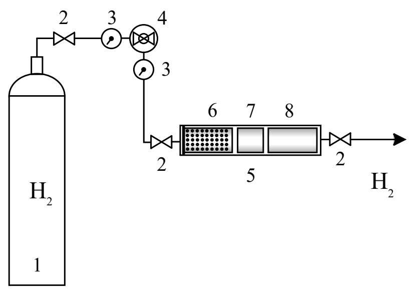

Fig. 2. Scheme of the unit for holding core samples exposed to hydrogen: 1-cylinder with compressed gas (hydrogen); 2-inlet and outlet valves; 3-pressure sensors; 4-pressure reducer with a valve; 5-sealed cylinder with rock samples; 6-sieve with a crushed rock; 7-standard core sample (diameter and length 3 cm); 8-longer core sample (diameter 3 cm, length 6 cm).

ε'_{2b} are the relative transverse strain of the sample at the end and beginning of a given range during destressing.

Stage 3: At this Stage, the samples were subjected to long-term exposure to hydrogen. For this purpose, the unit shown in Fig. 2, was used. The unit consisted of three main parts: 1) Balloon with hydrogen, 2) pressure reducer with pressure sensors and 3) sealed cylinder. This is considered in more detail below:

1) Hydrogen is supplied to the core samples from a cylinder with compressed gas (Fig. 2). The cylinder volume is 40 dm^3, the gas amount in which is 6.3 m^3. The quality and characteristics of pure hydrogen gas comply with the requirements of GOST R 51673-2000.
2) Pressure reducer with gas pressure sensors at the inlet and outlet of the reducer was installed due to the high pressure of hydrogen in the cylinder (Fig. 2). The decrease in gas pressure was approximately 0.6-0.7 MPa.
3) Sealed cylinder (Fig. 2) is designed for rock samples placement. It has inlet and outlet openings for gas injection and discharge. Each series of studies consisted of placing one standard sample, one longer sample and a crushed sample soaked in distilled water and placed in a special sieve inside the cylinder to exclude its removal from the cylinder during gas pumping.

The sequence of this Stage covers a few steps. Firstly, a reducer and a cylinder with rock samples were connected to the hydrogen cylinder, while a certain volume of air was passed through in order to displace the air in the cylinder. Secondly, the outlet valve was closed, and then the inlet valve, and the rock was kept for 7 days, while the gas was updated once a day. The experiment involved 5 groups of samples which consisted of one standard core, one longer core and a crushed rock to study changes in its chemical composition.

Stages 4, 5: After the samples were exposed to hydrogen, by analogy with Stages 1, 2 (Table 1), density and dynamic characteristics of samples (Table 1, Stage 4) and stress-strain properties were again determined by the static method (Table 1, Stage 5).

In experiments, the error in measuring the Young's modulus, Poisson's ratio and tensile and compressive strength by the static method is no more than 2%. The measurement error for the wave travel time is 0.5 microseconds and for the density of the rock is 0.005 g/cm^3. This accuracy is sufficient to compare the characteristics obtained during research, since they change by a large amount.

3. Results of studies

A comparison of changes in physical and mechanical properties before and after exposure to hydrogen is given in Tables 2, 3 and Figs. 3-7. Figs. 3-5 show a comparison of density and dynamic characteristics. For a more convenient comparison, a line of equal values is drawn by dots on each diagram. By comparing the values obtained experimentally with this straight line, it is possible to determine whether a change in a certain characteristic occurring after exposure to hydrogen led to its decrease or increase. Thus, if the dots are below the line of equal values, the considered rock property decreased; if they are above the line, it, on the contrary, increased.

Figs. 3-5, 7 show an approximating function of linear form starting from the origin of coordinates. Based on the coefficient at variable x of this function, it is possible to determine by what percentage the characteristic changes.

In general, the results show that some of the obtained characteristics change to a certain extent: Part of them increased (Young's modulus, density), while the others decreased (interval transit time of P and S waves).

Stress-strain properties of rocks determined by the static method are presented in Table 3 and Fig. 6. Several core samples destroyed as a result of core studies by the static method were crushed and used for subsequent chemical analysis of the rock before and after exposure to hydrogen (Popov et al., 2023). Thin sections were made from several destroyed samples to study their lithological and petro-physical properties. The results of lithological-petrophysical studies and chemical analysis of the rock are presented in the previous publication by the authors (Popov et al., 2023).

Laboratory experiments with static tests revealed a significant scatter of values for all four determined characteristics (Fig. 6), which is associated with the research methodology according to which paired core samples were studied, since in the process of static tests samples are destroyed.

Analysis of the obtained results presented in Tables 2-3 and Figs. 3-7, show that after exposure to hydrogen, Young's modulus and density increase by 10% and 1%, respectively; Poisson's ratio remains virtually unchanged; interval transit time of P and S waves decreases by about 3%. Despite an obvious change in the above characteristics, their absolute change is not so significant.

Based on the analysis of changes in elastic properties as well as density, it can be concluded that after exposure to hydrogen, compaction of the samples occurs. This is also evidenced by a decrease in interval transit time of P and S waves (Fig. 5). These characteristics decrease due to an increasing wave transit velocity, which is also a consequence of rock compaction. In the opinion of the authors, such rock

Table 2. Changes in the density and dynamic characteristics of core samples after exposure by hydrogen.

Group	Sample	Absolute change					Relative change				
		Δt_p (ms)	Δt_s (ms)	$\Delta \rho$ (g/cm^3)	ΔE_{dyn} (GPa)	$\Delta \nu_{\mathrm{dyn}}$ (f.u.)	Δt_p (%)	Δt_s (%)	$\Delta \rho$ (%)	ΔE_{dyn} (%)	$\Delta \nu_{\mathrm{dyn}}$ (%)
1	19	-3	-7	-0.01	0.15	0.054	-0.77	-0.80	0.34	0.15	0.054
	2/1	-10	3	0.01	0.08	0.039	-2.38	0.33	1.22	0.08	0.039
2	12	1	-34	0.01	0.73	0.030	0.27	-4.21	0.83	0.73	0.030
	14	-7	13	-0.02	-0.08	0.023	-1.80	1.61	1.37	-0.08	0.023
3	15	-3	-94	0.06	3.47	0.005	-0.93	-13.5	1.28	3.47	0.005
	5/1	-11	-34	0.02	0.77	0.036	-2.68	-3.98	2.00	0.77	0.036
4	3	-32	-10	0.02	0.26	0.054	-7.17	-1.05	0.49	0.26	0.054
	8/1	-15	6	0.04	0.13	0.024	-3.62	0.71	1.84	0.13	0.024
5	21	-9	-2	-0.01	0.18	0.042	-2.49	-0.27	0.58	0.18	0.042
	8/2	-22	-84	0.05	1.54	0.047	-5.37	-9.15	2.43	1.54	0.047
Mean value		-9.9	-18	0.02	0.63	0.030	-2.40	-2.35	1.11	6.46	0.03

Table 3. Changes in the elastic-strength properties of core samples determined by the static method after exposure by hydrogen.

Group	Sample	Absolute change				Relative change			
		ΔE_{stat} (GPa)	$\Delta \nu_{\mathrm{stat}}$ (f.u.)	$\Delta \sigma_c$ (MPa)	$\Delta \sigma_t$ (MPa)	ΔE_{stat} (%)	$\Delta \nu_{\mathrm{stat}}$ (%)	$\Delta \sigma_c$ (%)	$\Delta \sigma_t$ (%)
1	19	-4.63	-0.140	1.7	1.63	-52.1	-74.1	4.95	74.8
2	12	0.60	-0.180	6.4	0.85	7.23	-70.6	21.3	34.7
3	15	-0.23	-0.001	12.6	-2.22	-2.28	-0.3	32.1	-73.8
4	3	1.19	-0.144	4.6	-1.42	14.1	-45.1	14.3	-45.5
5	21	-3.88	-0.108	-10.7	0.41	-35.7	-32.9	-23.4	16.6
Mean value		-1.39	-0.11	2.93	-0.15	-13.7	-44.6	9.86	1.36

compaction was a consequence of the impact of overburden pressure during studies of reservoir properties (Popov et al., 2023) after weakening of rocks under exposure to hydrogen. As shown in articles (Pettersen, 2010; To and Chang, 2019; Zhukov and Kuzmin, 2021), similar effects show up in both carbonate and terrigenous reservoirs and are caused by the ability of the reservoir to compress with increasing effective stresses. Apparently, exposure to hydrogen disrupted the strength of intergranular contacts, which led to a certain weakening of the rock.

The study of stress-strain properties by the static method (Fig. 6) did not show a significant change in these characteristics before and after exposure to hydrogen.

This effect is due to the fact that the properties were studied on "paired" core samples, because the samples are destroyed during the experiment. Based on the analysis of the results of static studies of the stress-strain properties of core samples, the following can be noted after exposure to hydrogen: Young's modulus decreased by 13.7%; Poisson's ratio decreased by 44.6%; compression and tensile strength increased by 9.86% and 1.36%, respectively. At the same time, statistical analysis of the results of these studies did not reveal clear patterns of changes in these characteristics. This is due to the fact that because of limited technical capabilities, only 5 measurements of each characteristic were taken. In addition, the studies were performed on paired but different samples, which also introduces a certain scatter in the results of measuring these characteristics. To determine the obvious patterns, it is necessary to conduct more extensive research on the stress-strain properties of reservoir rock using the static method, at least on 15-20 core samples.

In addition to the above correlations, a close relationship was obtained between some other investigated properties of core samples (Fig. 7).

Based on Fig. 7, it can be concluded that after exposure to hydrogen the appearance of diagrams of functions reflecting

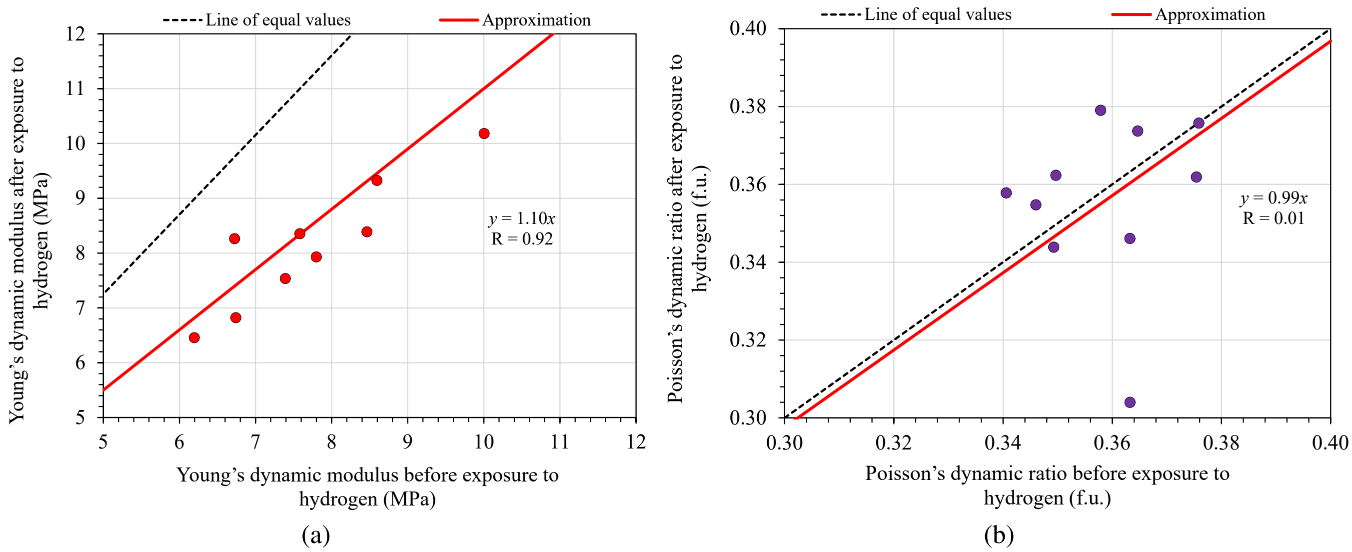

Fig. 3. Comparison of values of (a) dynamic Young's modulus and (b) Poisson's ratio of core samples before and after exposure to hydrogen.

the relationship between interval transit time of a S-wave and

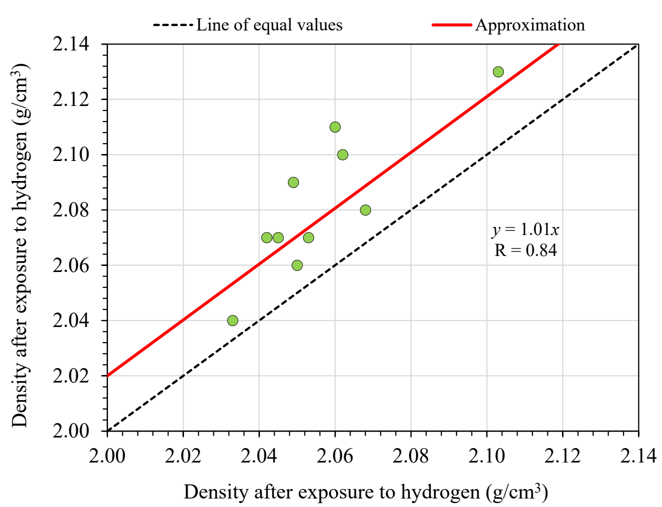

Fig. 4. Comparison of core samples density before and after exposure to hydrogen.

dynamic Young's modulus of core samples with interval transit time of a P-wave changed. All of the above-described patterns are, most likely, a consequence of changes in the structure of the void space of core samples due to disruption of intergranular contacts under the influence of hydrogen and their compaction when overburden pressure is created during the study of reservoir properties (Popov et al., 2023). Compaction of the rock leads to a decrease of the void space, which leads to an increase in the velocity of both the P-wave and S-wave, as well as an increase in the Young's modulus of the rock. This effect is shown on Fig. 7(a) in the form of a red shift of the graph to the left (a decrease in the travel time of the P-wave) and upward (an increase in the Young's modulus) after exposure to hydrogen. On Fig. 7(b), the effect of rock compaction leads to a shift of the red graph to the left and down, due to a decrease in the travel time of the P-wave and S-wave through the samples after exposure to hydrogen.

4. Conclusions

Along with salt caverns, one of the ways to store hydrogen is to pump it into depleted gas fields and aquifers. In this case, it is relevant to study the influence of hydrogen injection on porosity, permeability and physico-mechanical properties of reservoir rocks.

In connection with the above at this work the methodology and results of studies of the dynamic parameters, density and elastic-strength properties of a terrigenous reservoir before and after exposure of hydrogen are considered on the example of the Bobrikov deposits of the Volga-Ural oil-and-gas bearing region. The research methodology developed by the authors was used to assess the effect of hydrogen exposure on the physical and mechanical properties of a terrigenous reservoir. The authors chose the Bobrikov horizon as a hydrogen storage space due to its high permeability and the already created natural gas storage space in this reservoir.

The authors prepared core samples and conducted studies of the effect of hydrogen injection on the physical and mechanical properties of the rock by comparing the basic characteristics before and after exposure of hydrogen. As part of the experiments, the following parameters of the rock were studied: the interval travel time of the P-wave and S-wave, density, Young's modulus and Poisson's ratio (by static and dynamic methods), tensile and compressive strength limits.

An analysis of the results of determining elastic properties by the dynamic method showed that after exposure to hydrogen, the Young's modulus of core samples increased by 10%, while the Poisson's ratio practically did not change. The wave characteristics were transformed as follows: the interval travel time of the P-wave and S-wave decreased by about 3%. The experimental results showed that the density of the samples

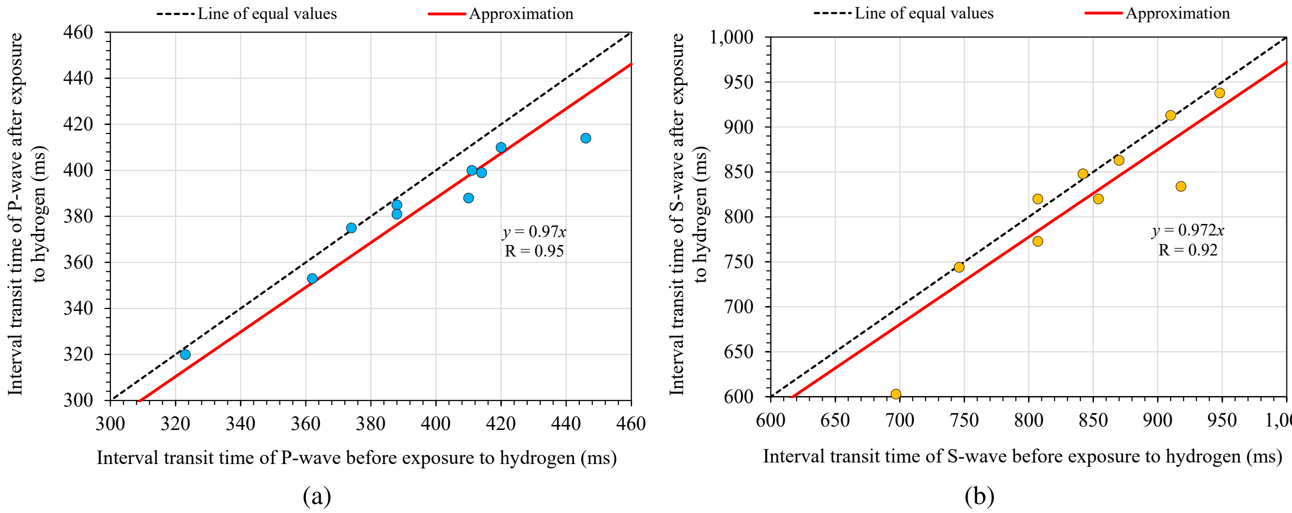

Fig. 5. Comparison of interval transit time values of (a) P wave and (b) S wave of core samples before and after ex-posure to hydrogen.

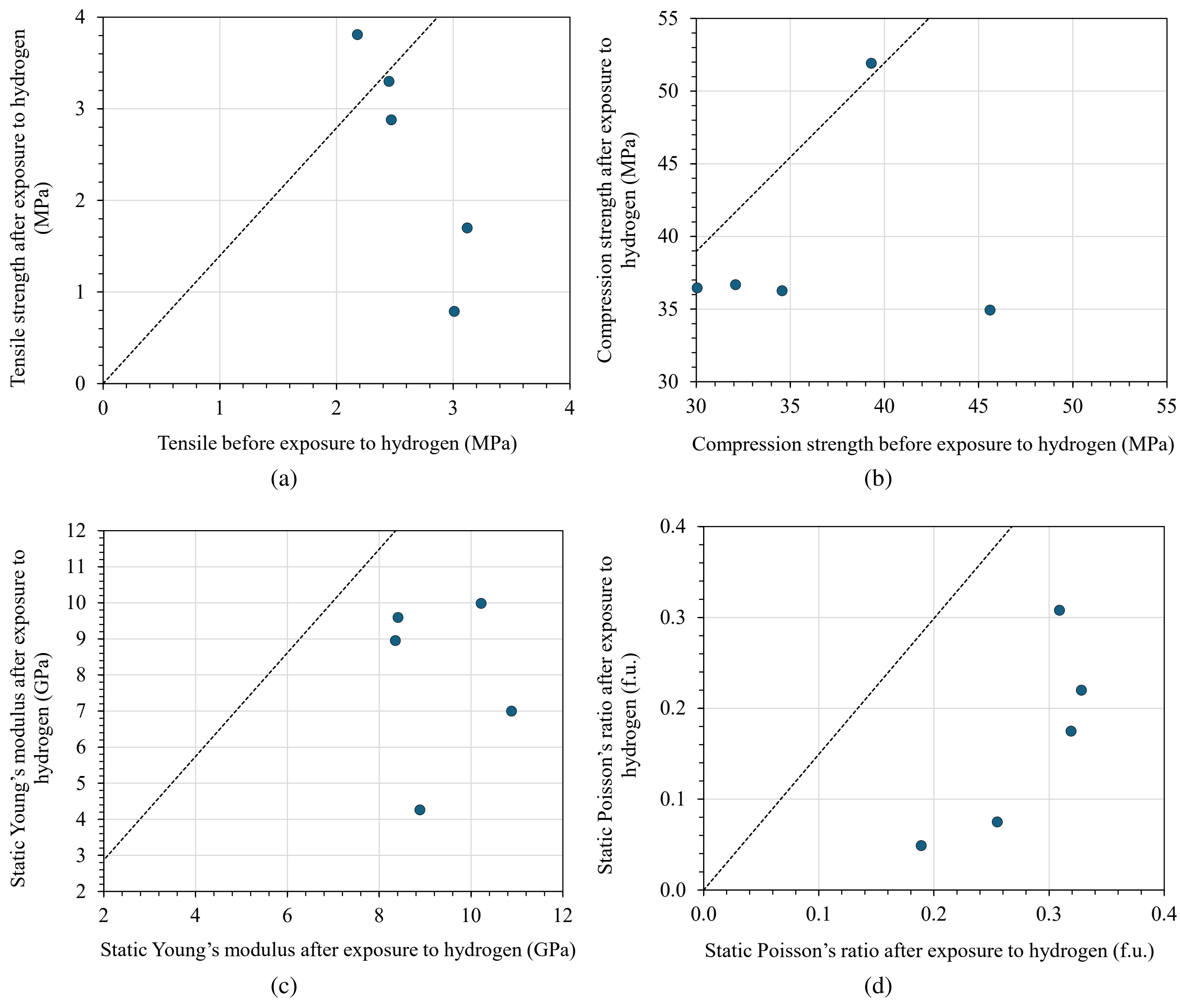

Fig. 6. Results of (a) determining tensile strength, (b) compression strength, (c) Young's modulus and (d) Poisson's ratio by static method for "paired" core samples (dotted line-line of equal values).

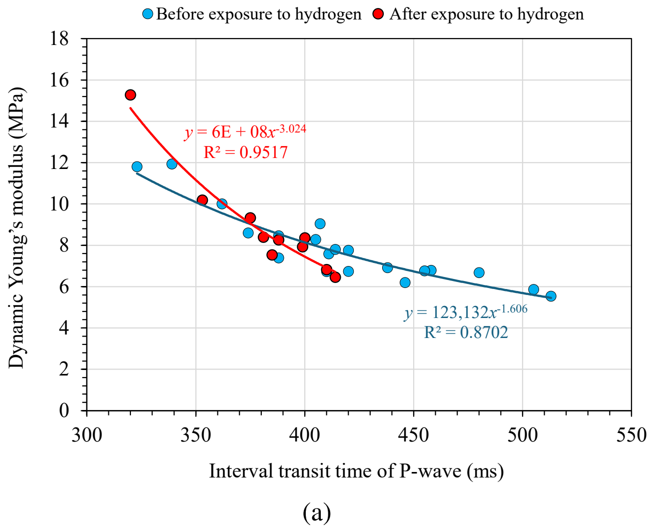

Fig. 7. Comparison of dependences of (a) dynamic Young's modulus and (b) interval transit time of S-wave on interval transit time of P-wave for core samples before and after exposure to hydrogen.

increased by 1%. Such rock compaction was the result of the weakening of rocks under the influence of hydrogen and their compaction in determining porosity and permeability. An increase in the dynamic Young's modulus of core samples after exposure to hydrogen is associated with rock compaction, more dense contact of solid particles and an increase in the velocity of the P-wave and S-wave.

The study of elastic-strength properties by the static method did not reveal obvious patterns in changes in these characteristics of core samples before and after exposure to water. This result could be due to the small number of samples studied, as well as the fact that "paired" samples were used for experiments, which initially could have different physical and mechanical properties. In this regard, for a more detailed study of the effect of hydrogen on the elastic and strength properties of reservoir rocks, further, larger-scale laboratory experiments with a much larger number of core samples are planned.

Based on the statistical analysis of experimental data, a characteristic change in the dependences of the dynamic Young's modulus and the interval time of the S-wave from the interval time of the P-wave was found. Such a change in patterns is most likely a consequence of a decrease in the strength of intergranular contacts and a change in the structure of the void space of core samples under the influence of hydrogen.

Analysis of the results of density, dynamic characteristics and elastic-strength properties of core samples studies allow us to conclude that the influence of hydrogen on the physical and mechanical properties of the reservoir rocks under consideration is very insignificant, which suggests that the object of research under consideration-the Bobrikov horizon in the Perm Region may be a potential object for hydrogen storage. The decrease in run speeds and rock density is very insignificant, which indicates a low degree of rock compaction when exposed of hydrogen. The above results indicate that the geological object under study (the Bobrikov formation) may be an object for storing a mixture of hydrogen and methane. At the same time, it is possible to confirm this conclusion to a greater extent only when conducting more detailed studies with a large number of samples and with a longer time of holding samples under the influence of hydrogen (up to one month or more), which is planned to be done in the future by the authors.

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Conflict of interest

The authors declare no competing interest.

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