EXLORING THE CHARACTERISTICS OF BACKFILL MATERIALS PROPOSED FOR WELL DECOMMISSIONING PURPOSES AT THE SITE OF ZHELEZNOHORSK LIQUID RADIOACTIVE WASTE DEEP DISPOSAL FACILITY

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The paper focuses on Portland cement and cement-bentonite mixture-based backfill materials. It presents the results of studies performed to assess the influence of factors affecting their performance and their protective properties considering the conditions inherent for the Zheleznogorsk liquid radioactive waste deep disposal facility. The following factors were considered as the key ones: type of the backfill material; chemical composition of the impacting aquatic environments in the injection horizons; temperature of the aqueous media containing heat-generating radionuclides. During the study, specified was the influence of these factors on the following protective properties of the formed backfill stones: strength, water resistance, tendency to defect formation. The results obtained can be used to develop closure designs for the Zheleznogorsk LRW DDF.

Keywords: *radioactive waste, deep disposal facility for liquid radioactive waste, backfill materials, Portland cement, bentonite clay, groundwater, physical and mechanical characteristics, wells.*

Introduction

Phased abandonment of underground facilities (production wells) [1] is seen as a most important task under the closure of deep well injection facilities for liquid radioactive waste (LRW) exiting in the Russian Federation. According to the preferred IAEA strategy, the safety of deep radioactive waste (RW) disposal facilities should be provided via the long-term containment of RW components in the geological environment through the use of passive engineered and natural safety barriers and RW isolation from the accessible biosphere [2]. Possible behind-the-casing overflows of radionuclide-containing liquids from deep horizons up along the production well boreholes pose greatest risks for the isolation of the disposed LRW from the accessible biosphere [3, 4].

To prevent behind-the-casing overflows of LRW components, design and engineering solutions for well abandonment should provide for the use of an effective engineered safety barriers system with the cement stone formed from plugging materials viewed as its element. The choice and the use of grouting materials depends on their ability to form impermeable compositions inside and outside the wells providing long-term retention of their insulating properties under the conditions of the available geological environment for the time period while the LRW components remain hazardous for the people and the environment. These considerations should also take into account possible migration of these components along the wellbore and near-wellbore space filled with grouting material.

The grouting materials should be adaptable to streamlined production, have rheological properties providing their pumpability through pipes to a given depth and have low water trapping. At the same time, after being pumped into the well, they must thicken penetrating the pores and the cracks and gain strength retaining their resistance to aggressive external influences of the geological environment.

Backfill Portland cement, bentonite and cement-bentonite mixtures are currently considered as materials suitable for RW isolation [5, 6]. Some brands of backfill Portland cement and its mixture with bentonite are considered of particular interest when it comes to the plugging of DDF LRW production wells at the abandonment stage.

Plugging stone evolution in the geological environment is influenced by a large number of factors. Natural factors are associated with the siting conditions, such as the availability of microorganisms, aggressive chemical compounds and gases in the formation water, as well as changes in the tectonic, geological, hydrogeological and climatic conditions within the siting region. Technological factors may involve such aspects as the composition of the grouting material and the technologies applied in the manufacturing of the grouting slurry and the construction of engineered safety barriers (modes of injection, cooling, etc.). Considering the above, the study was focused on the development of approaches and methods that could be used to evaluate the impact of individual factors affecting the protective properties of plugging materials under the conditions of a LRW disposal facility in Zheleznogorsk. The article considers the following variable factors: plugging material type; chemical composition of the impacting aquatic environments found within the production horizons; temperature of aqueous media containing heat-generating radionuclides. In the study, assessed was the influence of these factors on the characteristics governing the protective properties of the engineered safety barriers installed during the abandonment operations performed in the production wells (plugging stones): strength, water impermeability, tendency to defect formation.

Initial materials and research methods

Plain Portland cement PCT I-G-50 intended for use under low and normal temperatures corresponding to GOST 1581-96 was used as an initial material under the study [7]. To adjust its rheological and insulating properties, as well as its water trapping capacity, bentonite clay powder of BM-U type was applied as an additive. This additive is widely used in the oil and gas industry to produce aqueous clay solutions required to drill oil and gas wells and to adjust their properties [8]. It is also used in tunneling operations, in the construction according to the "buried wall" method to install impervious curtains, thixotropic jackets, etc.

Under the study, mixtures were produced according to the following ratio: 90 % of PCT I G-50 and 10 % of BM-U. The studied aqueous media involved:

- underground water of production horizons from the Zheleznogorsk DDF LRW site;
- a model solution simulating the chemical composition of LRW disposed of in the Zheleznogorsk DDF LRW.

The groundwater having a pH of 6 contained the following ions (in mg/dm^3): Fe (total) — 4.11; Na^+ — 57.75; Ca^{2+} — 36.34; Mg^{2+} — 10.02; NO_3^- — 0.5; SO_4^{2-} — 3.12; Cl^- — 11.11; F^- — 0.12; HCO_3^- — 293.05.

The model solution contained (g/dm^3): NaOH — 0.018; $NaNO_3$ — 350; Al^{3+} — 3.4; Cl^- — 0.5, as well as suspended solids in the amount of 30 mg/dm^3.

Under the study, the aqueous media directly affected the hardening of the plugging material samples. Figure 1 shows the appearance of the samples.

The samples were held in containers (with a capacity of no less than 6.2 liters each) made of a corrosion-resistant material with an aqueous medium in a climatic chamber at temperatures of 20 and 60 °C. The aqueous media acted chemically on the samples under a static mode. The model solution level was kept at least 1 cm above the samples.

Under the study, the volume of repaired model solutions was at least 2 times bigger than the capacity of each container. The solutions were stored in sealed reservoirs under the conditions provided for the storage of chemical solutions.

As part of the experimental studies, the following characteristics of plugging materials were investigated using standardized techniques:

- fabricated samples of plugging materials were measured to identify their mass and density in accordance with GOST 310.4-81 [9];
- ultimate tensile strength and ultimate compressive strength were measured in accordance with GOST 310.4-81 [9];
- insulating capacity was measured according to GOST 12730.5-84 [10].

Figure 1. Type of plugging material samples produced for testing purposes

Water permeability coefficients for the plugging stone were measured using the UVB-MG4.01 unit in accordance with the methodology provided in VSN 132-92 Rules for the Implementation of Operations Associated with Solution Injection Behind the Tunnel Lining and their Acceptance [11].

The phase composition of the cement stone was specified using a powder X-ray diffractometer ARL X'tra taking into account the methodological recommendations provided in ASTM 1365-06 [12].

Macro- and microdefects in the structure of the cement stone were identified based on X-ray microtomography using the SkyScan system taking into account the methodological recommendations from ASTM 1672-12 [13].

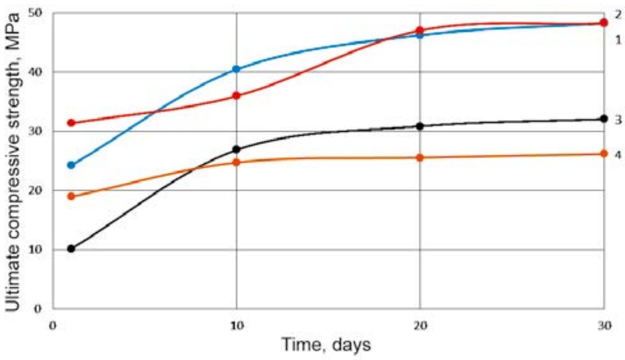
Corrosion rate within the cement stone, namely, in its surface layer was measured using scanning electron microscope Quanta 200 fitted with an X-ray spectrometer for elemental microanalysis (EDAX).

Characteristics of plugging materials were investigated at the initial stage of the plugging stone formation and up to the age of 30 days considering their exposure to natural water and model environments.

Evaluated physical and mechanical characteristics of plugging materials

According to the data obtained from the ultimate compressive strength measurements of the grouting material, shown in Figure 2, it was found that:

- increased exposure time to the model solution resulted in an increased ultimate compressive strength of the grouting material samples up to the age of 20 days, which basically got stabilized in the time interval of 20—30 days;
- 10% of bentonite added to the backfill Portland cement resulted in a lower ultimate compressive strength in comparison with the common backfill Portland cement over the entire time of its exposure to the model solution up to the age of 30 days;
- temperature increase (from 20 to 60 °C) resulted in an increased ultimate compressive strength of the grouting material samples during the initial period of the strength gain when held in a model solution;
- in case of backfill Portland cement samples, hardening in a model solution at a temperature of 60 °C resulted in a slowed down strength gain by the



1 — backfill Portland cement at an exposure temperature of 20 °C; 2 — backfill Portland cement at an exposure temperature of 60 °C; 3 — 90 : 10 (%) cement-bentonite mixture at an exposure temperature of 20 °C; 4 — 90 : 10 (%) cement-bentonite mixture at an exposure temperature of 60 °C

Figure 2. Time dependent changes in the ultimate compressive strength for plugging material samples interacting with a model solution

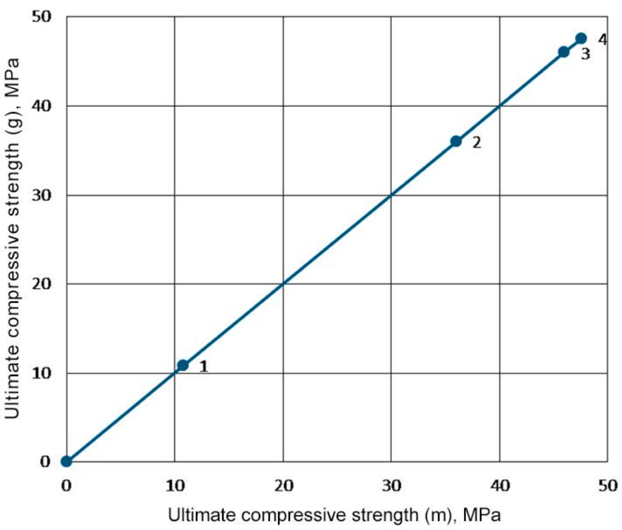
exposure time of 5 days and a gradually increasing strength gain rate by the exposure time of 20 days, followed by compressive strength stabilization to 46—47 Mpa similar to the level achieved after 30 days of exposure by backfill Portland cement samples that got hardened at a temperature of 20 °C.

- in case of backfill Portland cement samples with 10 % addition of bentonite, strength gain in a model solution at 60 °C got stabilized in 10 days reaching a level of 26 MPa, which has remained unchanged after 30 days as well. A 18—20 % decrease in the ultimate strength of the samples hardened at 60 °C was observed as compared to those hardened at a temperature of 20 °C.

The experiments showed that groundwater replacement with a model solution does not produce any significant effect on the compressive strength of backfill Portland cement at the age of 30 days. Figure 3 demonstrates that, in both cases, the experimental data can be plotted on a single straight line of constant composition along the entire investigated time interval referring to the impact produced by these aqueous media on the backfill Portland cement.

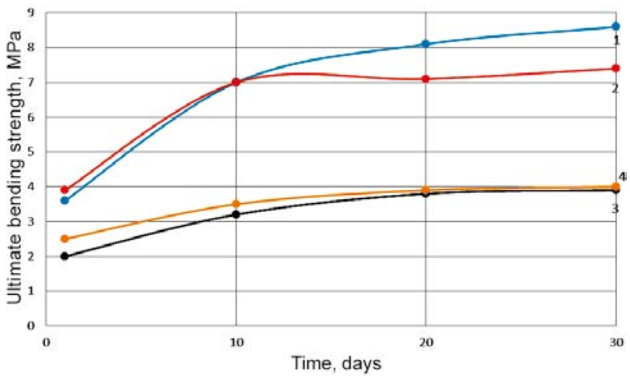
The impact of medium and exposure temperatures on the tensile bending strength of plugging materials was studied with relevant results summarized in Figure 4. It was found that:

- given an increased exposure time in a model solution, the tensile bending strength of the plugging material samples increases up to the age of 20 days and practically stabilizes within a time interval of 20—30 days;



Exposure time, days: 1 — 1, 2 — 10, 3 — 20, 4 — 30

Figure 3. Correlation between the ultimate compressive strength and the time for a backfill Portland cement sample being exposed to groundwater (g) and model solution (m) at a temperature of 20 °C



1 - backfill Portland cement at an exposure temperature of 20 °C; 2 - backfill Portland cement at an exposure temperature of 60 °C; 3 - 90:10 (%) cement-bentonite mixture at an exposure temperature of 20 °C; 4 - 90:10 (%) cement-bentonite mixture at an exposure temperature of 60 °C

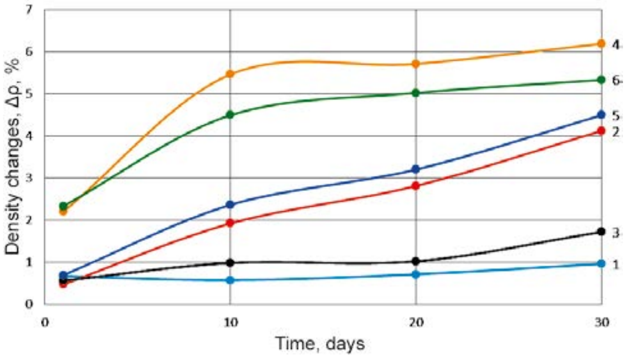
Figure. 4. Time dependent changes in the ultimate bending strength for plugging materials interacting with a model solution

- if compared with a backfill Portland cement, a 10 % addition of bentonite to the backfill Portland cement decreases the tensile bending strength over the entire exposure time in the model solution up to the age of 30 days;
- during the entire period of strength gain up to the age of 30 days, temperature increase (from 20 to 60 °C) practically does not produce any significant effect on the tensile bending strength of backfill Portland cement samples with a 10 % addition of bentonite being exposed to a model solution;
- backfill Portland cement samples hardened in a model solution at a temperature of 60 °C showed a 17—20 % decrease in tensile bending strength at the age of 10 days as compared with those exposed at a temperature of 20 °C.

Practically no effect on the tensile bending strength of plugging material samples was observed due to their exposure to groundwater. Figure 5 demonstrates the changes in the density of the plugging material samples.

Backfill Portland cement samples have shown an insignificant increase in their density along the entire period of their exposure to aqueous media at a temperature of 20°C. On the other hand, after 30 days of exposure, the maximum increase in the density amounted to 6 % as compared to the initial one.

Backfill Portland cements samples with a 10% addition of bentonite showed a density increase up to the age of 10 days followed by its subsequent stabilization. At an exposure temperature of 60 °C, density increase was observed for all plugging material samples along the entire period of their exposure to a model solution.



1 — backfill Portland cement interacting with a model solution at an exposure temperature of 20 °C; 2 — backfill Portland cement interacting with a model solution at an exposure temperature of 60 °C; 3 — backfill Portland cement interacting with groundwater at an exposure temperature of 20 °C; 4 — 90 : 10 (%) cement — bentonite mixture interacting with a model solution at an exposure temperature of 20 °C; 5 — 90 : 10 (%) cement — bentonite mixture interacting with a model solution at an exposure temperature of 60 °C; 6 — 90 : 10 (%) cement — bentonite mixture interacting with groundwater at an exposure temperature of 20 °C.

Figure 5. Changes in the density of plugging material samples depending on the exposure time to aqueous media

The insulating capacity of the studied plugging materials was measured. It was shown that given any of the varied conditions, their waterproof grade could be specified as grade W20 with the highest waterproofing index (there are some rare exceptions when these can be categorized as W18 grade), which corresponds to the air impermeability parameter of 0.0112—0.0077 cm^3/s and air penetration resistance of 88.6—130.2 s/cm^3. Scanning electron microscopy revealed no visible micro- and macro-defects in any of the studied samples (Figure 6), which indicated that after 30 days of exposure in ground water and a model solution, no effect was produced on the cement stone structure.

The microstructure of the studied plugging stone samples tends to be dense with no visible alterations, foci and signs of corrosion degradation.

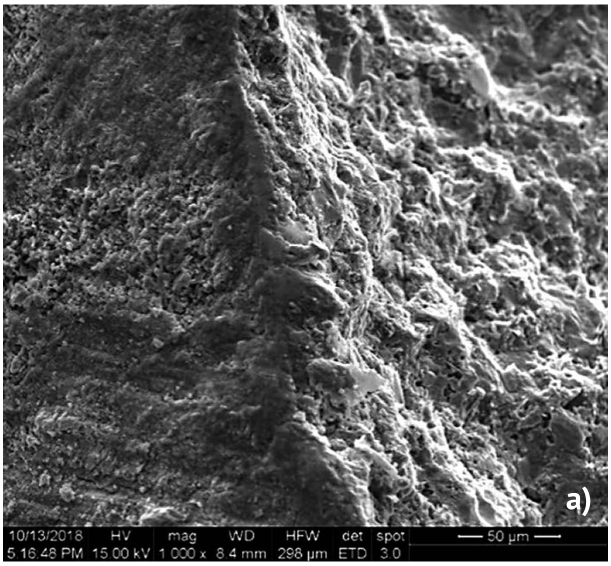
The research yielded in permeability coefficients K_f specified for different temperatures and various plugging materials:

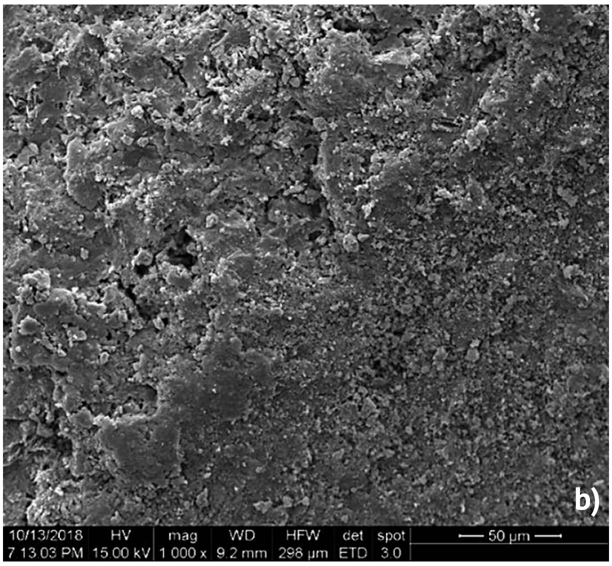
- $K_f = 5.7 \cdot 10^{-12}$ cm/s in case of backfill Portland cement and $K_f = 5.1 \cdot 10^{-12}$ cm/s in case of backfill Portland cement with a 10 % addition of bentonite given the exposure to both aqueous media at a temperature of 20 °C;
- at a temperature of 60 °C, $K_f = 5.5 \cdot 10^{-12}$ cm/s for both plugging materials after their exposure to ground water and $K_f = 5.1 \cdot 10^{-12}$ cm/s after their exposure to a model solution.

Phase composition of plugging materials: estimated evolution

Due to ongoing hydration reactions, the plugging material hardening in aqueous media changes its phase composition and causes the formation of the plugging stone microstructure. Therefore, this stage is responsible for the key physical and mechanical properties of the plugging stone.

Phase composition of the studied samples was investigated via the X-ray powder diffractometry method. During the X-ray phase analysis, samples from the upper layer formed due to the interaction of the aqueous medium and the cement stone were collected separately from the cement stone samples not being directly affected by the exposure solution. X-ray phase analysis was implemented





Surface / Depth boundary (1,000x magnification)

Figure. 6. Micrographs of the PCT I-G-50 sample on the 30th day of exposure to a model solution (a) and ground water (b) at 20 °C

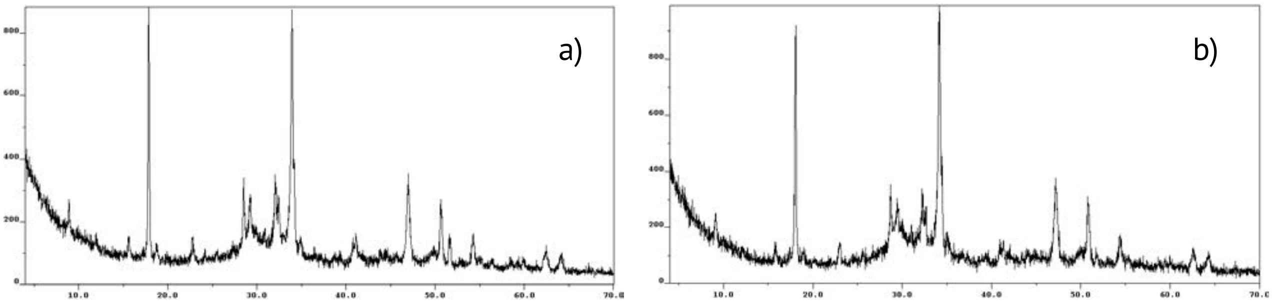
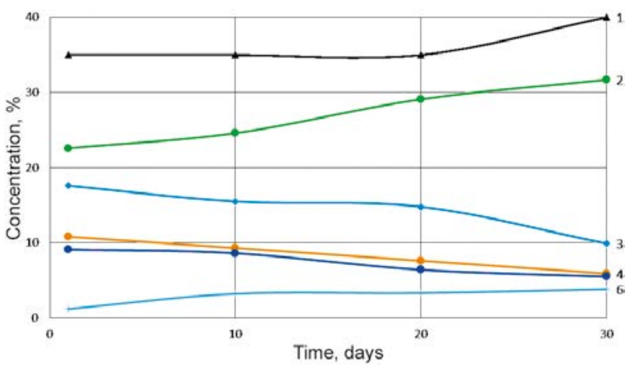


Figure 7. Registered diffraction patterns for a material layer of the PCT-I-G-50 sample at a depth of 2 mm given an exposure time of 10 (a) and 30 (b) days

considering some controlled time periods: 1, 10, 20, and 30 days of exposure to an aqueous medium. Figure 7 provides some examples of diffraction patterns recorded during the study.

The X-ray phase analysis has indicated some quantitative alterations in the phase composition of the cement stone at a depth of 2 mm from the sample surface happening over 1—30 days of sample exposure to aqueous media.

Alterations in the content of the main phases are typically associated with an increased content of amorphous component and portlandite in the cement stone composition and a decrease in the number of clinker phases along with the growing hydration of the samples. Gradual monotonic increase in the amount of calcium carbonate found in the samples should be noted as well, which is associated with the occurrence of carbonization reactions. Figure 8 shows the dynamics of changes in the phase composition of the cement stone during 30 days of exposure to ground water at a temperature of 20 °C.



1— amorphous phase; 2 — portlandite; 3 — alit; 4 — belite; 5 — tetra-calcium alumoferrite; 6 — calcite

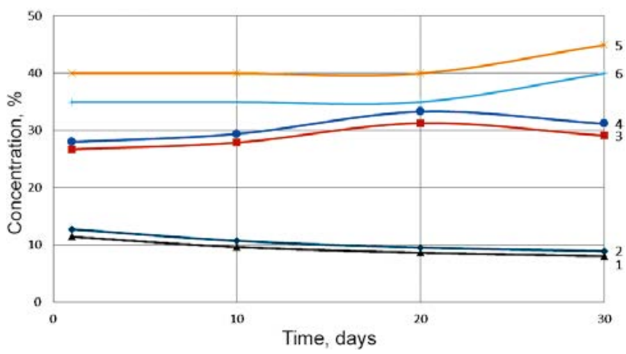
Figure 8. Evolution of phases (at a depth of 2 mm) considering the interaction of a backfill Portland cement sample with groundwater at an exposure temperature of 20 °C

The following processes occur during the backfill Portland cement hardening along with its structure formation:

- the content of unreacted cement clinker phases decreases: alite ($3CaO{\cdot}SiO_2$), belite ($2CaO{\cdot}SiO_2$), tetra-calcium alumoferrite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$);
- the content of amorphous phase (-C-S-H gel), portlandite [$Ca(OH)_2$] and calcite ($CaCO_3$) grows.

As it comes to the investigated plugging material samples hardened at a temperature of 20 °C, ettringite is viewed as their hydration product, whereas hydrogrant (katoite) was identified in case of samples hardened at a temperature of 60 °C.

Figure 9 summarizes the results of a comparative analysis focused on the evolution of sample phases considering the investigated plugging materials exposed to a model solution for 30 days.



1 — alite in a cement-benotnite mixture (90 % : 10 %) sample; 2 — alite in a backfill Portland cement sample; 3 — portlandite in a cement-benotnite mixture sample (90 % : 10 %); 4 — Portlandite in a backfill Portland cement sample; 5 — amorphous phase in a cement-benotnite mixture sample (90 % : 10 %); 6 — amorphous phase in a backfill Portland cement sample.

Figure 9. Evolution of plugging material phases at a depth of 2 mm considering their exposure to a model solution at 60 °C

Evaluated quantitative phase composition has demonstrated:

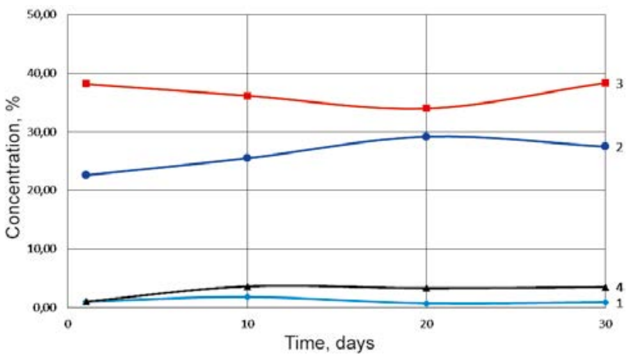
- that the dynamics of changes in the content of alite, portlandite and the amorphous component found in the compositions of plugging materials along their hardening and strength gain appears to be identical;
- a decreased content of portlandite after 20 days of plugging material hardening can be probably explained by the onset of the carbonization process.

High calcium carbonate content was found in the plaque composition on the surface of the studied plugging stone samples, which can be explained by the carbonization of portlandite formed during the hydration of cement phases according to the following reaction:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

Some amounts of sodalite ($3Na_2O{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}2NaCl$) and vishnevite ($Na_8(AlSiO_4)_6O_{24}(SO_4){\cdot}2H_2O$) were also found in the plaque composition on the surface of the plugging stone.

Figure 10 presents the changes in the content of portlandite found on the plugging stone surface compared against its content at a distance of 2 mm from the surface and the corresponding increase in the content of calcite found on the surface compared against its content found within the plugging material.



1 — portlandite on the sample surface; 2 — portlandite inside the sample (at a depth of 2 mm); 3 — calcite on the sample surface; 4 — calcite inside the sample (at a depth of 2 mm).

Figure 10. Evolution of phases in a backfill Portland cement sample considering its exposure to a model solution at 20 °C

For the plugging material samples, it was also found that at the initial stage of their exposure to aqueous media at a temperature of 20 °C, an increase in the content of calcium carbonate is followed by its stabilization by the 30th day. As for the samples exposed at a temperature of 60 °C, the same effect is observed at the 20th day of exposure, which indicates the compaction of the sample structure due to the pore clogging. Such clogging is associated with the carbonization products of portlandite and the discontinuation of portlandite transfer to the surface of the plugging material samples.

Conclusion

The considered approaches and methods proposed to evaluate the changes in the physical and mechanical properties of the backfill Portland cement and its mixture with 10% bentonite occurring due to its exposure to aqueous media representing the chemical composition of both groundwater found at operational horizons and the waste disposed of at the Zheleznogorsk DDF LRW allowed:

- to identify in which way the ultimate compression strength, bending strength and their density depend on the interaction time with aqueous media given different temperatures of the aqueous media;
- to specify the quantitative indicators characterizing the protective properties of plugging materials: water impermeability, permeability coefficient for the studied systems.

The data obtained demonstrating how the aqueous media can alter the protective properties of plugging materials refer to the onset of the hardening and strength gain processes, while the quantitative physical and mechanical characteristics and protective properties got stabilized by the 30th days of exposure to a model aqueous media.

Phase evolution in Portland cement and its mixture with 10 % bentonite due to its interaction with aqueous media was evaluated indicating the important role of portlandite in the changing composition of plugging materials depending on the varying conditions in which the reaction system — plugging material — aqueous medium exists.

Findings of this study can be applied as part of the activities implemented under the Zheleznogorsk LRW DDF closure plan development.

References

1. Ponizov A. V. Sistema organizatsionno-tekhnicheskikh mer po obespecheniyu bezopasnogo zakrytiya punktov glubinnogo zakhoroneniya zhidkikh radioaktivnykh otkhodov. Kontseptual'nyye polozheniya [System of Organizational and Technical Measures Providing Safe Closure of Deep Disposal Facilities for Liquid Radioactive Waste. Conceptual Provisions]. *Yadernaya i radiatsionnaya bezopasnost' — Nuclear and Radiation Safety,* 2020, no. 4, pp. 47—60. DOI: 10.26277/SECNRS.2020.98.4.005.

2. International Atomic Energy Agency. *Disposal of Radioactive Waste. Specific Safety Requirements.* No. SSR-5. IAEA. Vienna. 2011.

3. Ponizov A. V., Vereshchagin P. M., Chulkov N. V., Sharaputa M. K., Baidariko E. A. Usloviya, posledstviya i puti predotvrashcheniya zakolonnykh peretokov zhidkostey po stvolam skvazhin na uchastkakh glubinnogo zakhoroneniya zhidkikh radioaktivnykh otkhodov [Conditions, Consequences and Ways to Prevent Behind-the-Casing Fluid Flows Through Wellbores at the Sites of Deep Liquid Radioactive Waste Disposal Facilities]. *Geoekologiya. Inzhenernaya geologiya. Gidrogeologiya. Geokriologiya — Geoecology. Engineering geology. Hydrogeology.*

Geocryology, 2019, no. 2, pp. 56—57. DOI: 10.31857/S0869-78092019256-67.

4. Dorofeev A. N., Saveleva E. A., Utkin S. S., Ponizov A. V. et al. Evolyutsiya obosnovaniya dolgovremennoy bezopasnosti PGZ ZHRO [Evolution in the Safety Case for Liquid Radioactive Waste Geological Repositories]. *Radioaktivnyye otkhody — Radioactive Waste,* 2017, no. 1, pp. 54—63.

5. Varlakov A. P., Zherebtsov A. A., Petrov V. G., Kapustin V. V., Varlakova G. A., Vlasova I. E., Haritonov I. D., Kalmykov S. N. Otsenka radiatsionnykh i temperaturnykh nagruzok na tsementnyy kompaund, soderzhashchiy imitatory radioaktivnykh" otkhodov [Assessment of Radiation and Temperature Loads on Cement Compound Containing Simulated]. *Radioaktivnyye otkhody — Radioactive Waste,* 2020, no. 1 (10), pp. 66—72. DOI: 10.25283/2587-9707-2020-1-66-72.

6. Krupskaya V. V., Zakusin S. V., Lekhov V. A., Dorzhieva O. V., Belousov P. E., Tyupina E. A. Izolyatsionnyye svoystva bentonitovykh bar'yernykh sistem dlya zakhoroneniya radioaktivnykh otkhodov v nizhnekanskom massive [Buffer Properties of Bentonite Barrier Systems for Radioactive Waste Isolation in the Geological Repository of the Nizhnekanskiy Massif]. *Radioaktivnyye otkhody — Radioactive Waste,* 2020, no. 1 (10), pp. 35—55. DOI: 10.25283/2587-9707-2020-1-35-55.

7. GOST 1581-96. *Portlandtsementy tamponazhnyye. Tekhnicheskiye usloviya* [Backfill Portland cements. Standard Specifications].

8. Pustovgar A. P., Abramova A. Yu., Eremina N. Ye., Ganiev S. R. Issledovaniye vozmozhnosti chastichnogo zameshcheniya portlandtsementa kvartsevoy mukoy Silverbond v sostave tamponazhnykh materialov [Study of Possible Partial Replacement of Portland Cement with Silverbond Quartz Flour in the Composition of Backfill Materials]. *Stroitel'stvo neftyanykh i gazovykh skvazhin na sushe i na more — Construction of Oil and Gas Wells on Land and at Sea,* 2019, no. 8, pp. 27—36. DOI: 10.30713/0130-3872-2019-8-27-36.

9. GOST 310.4-81. *Tsementy. Metody opredeleniya predela prochnosti pri izgibe i szhatii* [Cements. Methods Used to Determine its Ultimate Cross-bending and Compression Strength].

10. GOST 12730.5-84. *Betony. Metody opredeleniya vodonepronitsayemosti* [Concrete. Methods Used to Determine its Water Tightness].

11. VSN 132-92. *Vedomstvennyye stroitel'nyye normy. Pravila proizvodstva i priyemki rabot po nagnetaniyu rastvorov za tonnel'nuyu obdelku* [Institutional Building Codes. Rules for the Execution and Acceptance of Work Associated with Solution Injection Behind the Tunnel Casing].

12. ASTM 1365-06 (2011). *Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker Using X-Ray Powder Diffraction Analysis.*

13. ASTM l672-12. *Standard Guide for Computed Tomography (CT) System Selection.*

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