Decrease of radon permeability in cement concrete and solutions

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Abstract. The article presents special research aimed at the estimation of radon permeability change in cement-sand solution after applying a padding layer of the gypsum on its surface during the process of forming the additional layer of gypsum paste to decrease radon permeability of cement concretes and solutions.

1. Introduction
Based on earlier domestic and international research it has been established that the presence of gypsum as a part of cement affects hydration processes and the structure of a liquid phase significantly [1-4].

Gypsum, being an additional source of calcium ions in a liquid phase, creates conditions for formation of hardly permeable hydrosulfoaluminate membranes which are formed according to the scheme (1) on the surface of a clinker grain [5, 6, 7].

\[ C_3A + 3CSH_2 + 25H_2O = C_3A(SH)_{25} \] (1)

In this regard the speed of cement hydration decreases. The process of forming and hardening of a submicrocrystalline structure around cement grains is followed by the increasing tensions because of hydration products’ accumulation on their surface, therefore cracks are formed in the membranes and water that gets through them activates the hydration process again. Then the saturation process of a liquid phase by ions repeats and new submicrocrystals which can fill in the defects are formed. [3, 8-11].

Due to what is said above, the question of a possibility to use this effect to decrease radon permeability of cement concretes and solutions seems to be interesting. For this purpose specific research aimed at estimating radon permeability change in cement-sand solution after applying a padding layer of gypsum during the process of forming the additional layer of gypsum paste on its surface has been done.

2. Methods
The influence of gypsum coverings on the structure has been studied by the methods of X-ray phase analysis and the differential thermal analyses (DTA). Figure 1 shows the diffraction pattern of a cement-sand solution test from a lateral face of a two-layer sample, and Figures 2 and 3 show the diffraction pattern of solution tests in the contact zone “cement- sand solution- gypsum stone” at the depth of 1 and 2 mm respectively.

The mineralogical composition of cement solution is presented generally by quartz [SiO2] with diffraction maximums of \( d = 0,182; 0,198; 0,212; 0,223; 0,228; 0,245; 0,335; 0,425 \) nm. On a
diffraction pattern there are also peaks of feldspar \((d = 0.320; 0.402 \text{ nm})\) and calcium carbonate \([\text{CaCO}_3] \ d = 0.303 \text{ nm}\).

![X-ray diffraction pattern of cement-sand solution from a lateral face of the sample.](image1)

**Figure 1.** X-ray diffraction pattern of cement-sand solution from a lateral face of the sample.

![Diffraction pattern of a "solution-gypsum" contact side at the depth of 1 mm.](image2)

**Figure 2.** Diffraction pattern of a "solution-gypsum" contact side at the depth of 1 mm.
Figure 3. Diffraction pattern of a "solution-gypsum" contact side at the depth of 2 mm.

The diffraction patterns of a “solution-gypsum” contact side at the depth of 1 and 2 mm of the solution layer are almost identical. Feldspar peaks with interplanar distances of $d = 0.402; 0.320$ nm are accurately identified. Also there are peaks of Ca(OH)$_2$ with interplanar distances of $d = 0.263; 0.190$ nm and unhydrated minerals of a portland cement $C_3S$ and $S_2S$ ($d = 0.277; 0.268$ nm). In the tests the existence of the main peaks of $C_2S$, $CSH$ hydroxilicates ($d = 0.384; 0.280; 0.285; 0.182$ nanometers) as well as the presence of a low-sulphatic form of $C_3ASH_2$ hydrosulfoaluminate ($d = 0.287; 0.245$ nm) with imposing unhydrated cement minerals on the peaks has been noted. Orthoclase peaks ($d = 0.644; 0.293; 0.265$ nm) and quartz SiO$_2$ ($d = 0.4245; 0.223; 0.198$ nm) are visible.

The distinctive feature of the diffraction pattern is the emergence of ettringite peaks emergence ($3CaO-Al_2O_3-3CaSO_4-31H_2O$) with interplanar distances of $d = 0.560; 0.469; 0.222$ nm.

Figures 4, 5, 6 show the thermograms of these tests.

The endothermic effects, considerable in size, with maxima at temperatures of 130, 525, 580, 865, 870 and 880 °C are observed on the thermograms.

The endothermal effect at the temperature of 130-150 °C characterizes dissociation of a high sulphate form of calcium hydrosulfoaluminates (GSAC) and at 525°C and 580°C dissociation of Ca(OH)$_2$.

The endothermal effects in the temperature range of 865-880 °C are caused by decarbonation of calcium carbonate. Fig. 5 and 6 show clearly that the size of the peak demonstrating GSAC dissociation in the tests of a “solution-gypsum” contact side selected at the depth of 1 and 2 mm is much bigger, than it is in test of a cement solution from the lateral face of the sample, which is not contacting to gypsum.
Figure 4. The thermogram of cement solution from a lateral face of the sample.

Figure 5. The thermogram of a "solution-gypsum" contact side at the depth of 1 mm.
Thus, as a result of X-ray phase analysis and DTA it has been established that on the boundary of phases between gypsum and cement-sand solution the additional amount of calcium hydrosulfoaluminate is formed. GSAC has much smaller density than main products of cement hydration (hydrosilicate and hydroaluminate) due to the considerable water content (31H$_2$O) in a crystal lattice. Being formed in a pore space of a cement stone, GSAC colmatage pores, in our opinion, this is the reason of sharp fall off of radon diffusion through the samples.

By the results of tests with applying an additional layer of the gypsum paste and gypsum-containing substance of various thickness – kek - it is established that the increase of the sample gypsum covering thickness does not increase its radon diffusive resistance (tab. 1). To achieve the effect of sharp decrease of the diffusion coefficient (DC) of cement concrete and solutions it is enough to meet the condition of forming a contact zone of cement composition with a gypsum covering.
Table 1. The structures and settlement DC of cement-sand solution samples with applying an additional gypsum-containing layer.

| Material                                      | Structure          | Thickness, m | Settlement DC, m²/c |
|-----------------------------------------------|--------------------|--------------|---------------------|
| Cement-sand solution, with gypsum paste covering (W/G = 0.55) |                     |              |                     |
| Cement, kg         | 479                | Sand, kg     | 1436               | Water, l            | 335               | Cement-sand solution | 0.035 | Covering | 0.015 | 1.83·10⁻⁸   |
|                    |                    | Covering      |                     |                     |                   |                          |       |           |       |             |
| Cement-sand solution, with gypsum paste covering (W/G = 0.55) |                     |              |                     |
| Cement, kg         | 479                | Sand, kg     | 1436               | Water, l            | 335               | Cement-sand solution | 0.060 | Covering | 0.005 | 2.08·10⁻⁸   |
|                    |                    | Covering      |                     |                     |                   |                          |       |           |       |             |
| Cement-sand solution, with gypsum paste covering (W/G = 0.6) |                     |              |                     |
| Cement, kg         | 472                | Sand, kg     | 1417               | Water, l            | 331               | Cement-sand solution | 0.042 | Covering | 0.020 | 3.97·10⁻⁸   |
|                    |                    | Covering      |                     |                     |                   |                          |       |           |       |             |
| Cement-sand solution, with kek covering (W/K = 1.3) |                     |              |                     |
| Cement, kg         | 479                | Sand, kg     | 1436               | Water, l            | 335               | Cement-sand solution | 0.035 | Covering | 0.010 | 0.49·10⁻⁸   |
|                    |                    | Covering      |                     |                     |                   |                          |       |           |       |             |
| Cement-sand solution, with kek covering (W/K = 1.3) |                     |              |                     |
| Cement, kg         | 472                | Sand, kg     | 1417               | Water, l            | 331               | Cement-sand solution | 0.042 | Covering | 0.010 | 2.50·10⁻⁸   |

3. Results and Discussion

On average the effective diffusion coefficient of construction solutions processed by gypsum or kek is nearly 1.8 times less than DC of cement concrete and 3.2 times less, than in cement-sand solutions (Figure 7).

Thus, to solve the problem of increasing the security degree of buildings from penetration of radon to the soil it is offered to arrange monolithic screed based cement binding agent over an additional protective gypsum concrete layer organized on freshly laid concrete.

This radon-protective barrier can be also considered as a floor design of building basements in case of weak intensity of mechanical influences and conducting construction on dry. In this case, it is allowed to apply a clay-containing concrete bottom set. It is offered to use gypsum with the grade on compressive strength not less than 15 MPa as a material of an interlayer over which cement-sand covering is put as a floor top layer (fig. 8).

Figure 8. Constructive scheme of a radon-protective barrier
Most often, in practical experience, floor constructions are the most difficult to design as it is necessary to comply with additional common technical rules, technological, hygiene and sanitary and operating requirements and norms of specific buildings and constructions design [12].

If the most general case is considered, the design of a floor consists of the bottom set distributing loads on soil; screed for alignment of a underlying layer surface of the floor, giving the set bias; the shelter of various communications and distribution of loadings on non-rigid underlying layers; the waterproof layer preventing penetration of sewage and other liquids through the floor and also penetration of ground waters as a result of a capillary raising; the layer connecting the covering with an underlying floor layer and serving as an elastic bed and the covering which is directly exposed to operational influences [13].

According to the Code of practice 29.13330.2011 it is also recommended to apply gypsum screed which durability has to be not less than 20 MPa, in dried up to the constant weight conditions in case of application under bulk polymeric coverings and in other cases not less than 10 MPa as an element of floor design. Thus, it is possible to arrange a highly effective radon-protective barrier with a combination of layers made of gypsum and portlandcement binder to achieve the effect of ettringite formation in a contact zone of layers with a function of a floor in the basements.

Besides, if to lay the waterproof material preventing penetration of soil moisture into the floor construction not by a traditional method, but namely under a screed, that doesn't contradict to the requirements of the Code of practice, then the effect of a barrier radon protection will increase considerably due to the formation of the second "gypsum concrete-cement-sand solution" contact zone. The construction scheme of this floor design is presented on Fig. 9 [14].

![Construction scheme of a radon-protective barrier.](image)

**4. Conclusions**

The application of these barriers with lower radon permeability in comparison with traditional ones will provide decrease the population radiation level in the building premises.
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