Experimental study of crystalline rock filtration properties: implications for underground radioactive waste disposal

A. V. Zharikov[1,2], V. I. Velichkin[1], V. M. Vitovtova[2], V. I. Malkovsky[1], V. M. Shmonov[2]
[1]Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, RAS, Moscow, Russia
[2]Institute of Experimental Mineralogy, Russian Academy of Sciences, Chernogolovka, Russia

vil@igem.ru

The results of transport properties of tight rocks studies, their interpretation and use for search of the area for safe underground deposition or reposition of HLW and SNF on the basis of the data of physical and numerical experiments were considered. The rock samples collected from the sites of probable location of HLW and SNF depositories or repositories: metavolcanites from the area of PA Mayak. and granitoids from the Krasnoyarsk MCC zone were used for the laboratory study. On the basis of the comparative analysis of the experimental data and the results of microstructure studies the main factors controlling rock transport properties were found. A forecast of permeability changes under heating due to HLW heat-generation was done. It was considered how to determine intact rock thicknesses enough for safe location of HLW depositories using the results of physical experiments as input data for a numerical one.

Key words: rock porosity and permeability, numerical and physical simulation, well HLW depositories

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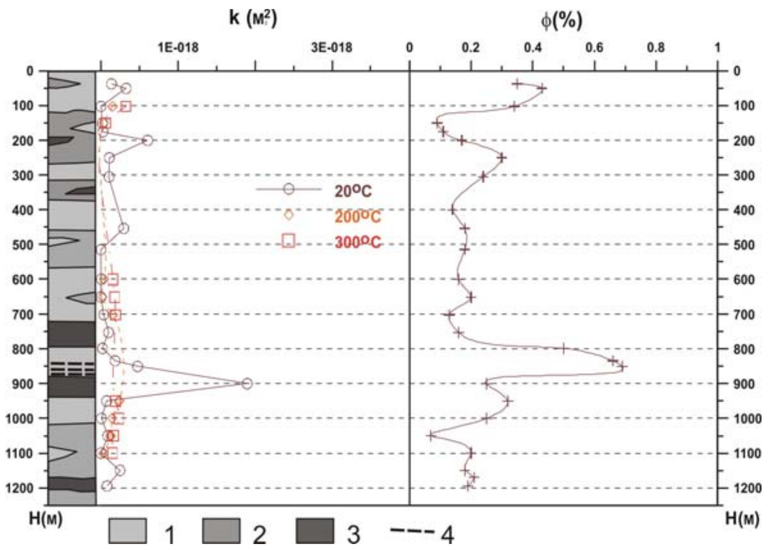
Main requirement for the area selected for location of underground depositories or repositories of HLW or SNF is to minimize the risk of radionuclide escape with underground water to the biosphere. So, an importance of studies of rock transport properties is evident. First of all it concerns rock permeability which is one of the main factors governing dynamics of natural and technogenic fluids flow in the geologic media. Permeability values for tight rocks occurring near the HLW and SNF depositories or repositories are usually very small so their determination is strongly difficult. Therefore the authors developed a special technique for permeability laboratory studies taking into account the peculiarities of gas filtration through tight rocks. Permeability determinations are carried out with respect to changes in filtrating gas properties due to temperature and pressure effects. That allows to perform the measurements with high accuracy within wide range of values (10^{-22}–10^{-15} m^2) at normal and high *PT*-parameters as well. The data obtained in a single test are enough to determine both the values of sample permeability and Klinkenberg factor, characterizing pore shape. Against the conventional methods the measurement accuracy and work content are improved and recording of experiment parameters is simplified.

The studies of transport properties on the samples of the main rock types from the areas of probable location of HLW and SNF depositories or repositories: metavolcanites from the area of PA Mayak (Sothern Ural) and granitoids from the Krasnoyarsk MCC zone (Yeniseian ridge) were carried out with use of the new technique (fig. 1–4).



a b

Fig. 1. Permeability (a) and porosity (b) of the samples from the well 8001 and 8002 of Mars-2 site, PA Mayak
1 – tuff, tuff lava; 2 – lava-breccia, 3 – porhyritic andesite-basalt, 4 – schistose rock.

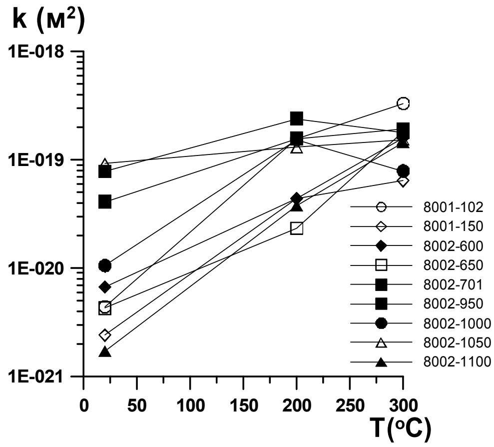


Fig. 2. Temperature dependencies of permeability for the samples from the well 8001 and 8002 of Mars-2 site, PA Mayak. P_{eff}= const = 25 MPa.

The results obtained show that beyond the dislocations zones metavolcanites have low values of porosity and permeability. Porosity of the samples varies from 0.07 to 0.69 %, the mean value is 0.26 %. Most of the studied samples also show very low permeability: its values for 17 of 27 samples does not exceed 10^{-19} m^2, mean value is $1.92 \cdot 10^{-19}$ m^2. It is significant that the background permeability values, even taking into account their rise with heating, are considerably lower than that obtained for the samples collected in the schistosity zone under ambient conditions. So, an occurrence of the families of microcracks related to the rock structure, in this case to rock schistosity, is more dangerous factor reducing insulating properties of the rocks of HLW near field than their thermal decompaction.

Permeability values of granitoid samples are also quit low: 0.14 – 0.95 %. (fig. 2. b). Mean values for the site are close: 0.44 % for Itatsky site and 0.37 % for Kamenny one, for both sites – 0.41 %.

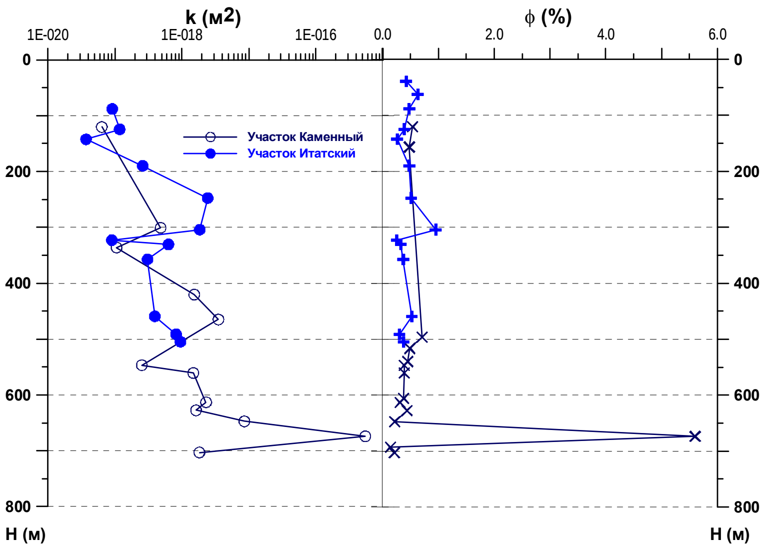


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Fig. 3. Permeability (a) and porosity (b) of the samples from the well 1I-500 and 1K-700 drilled in the the Itatsky and Kamenny sites, Krasnoyarsky MCC.

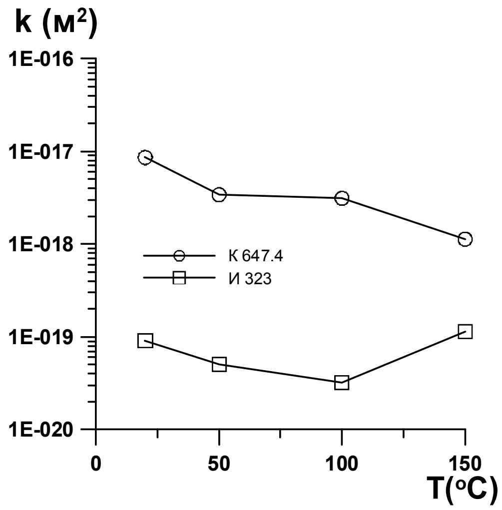
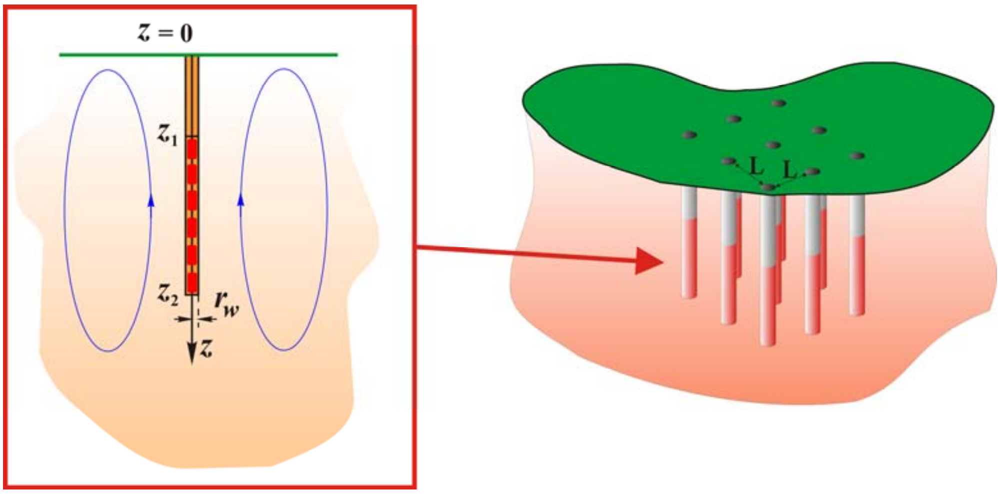


Fig. 4. Temperature dependencies of permeability for the samples from Nizhnekansky massive.
P_{eff}= const = 25 MPa.

Permeability values for most of studied granitoid samples varies from $3.71 \cdot 10^{-20}$ to $8.59 \cdot 10^{-18}$ m^2. Mean value for both sites is $1.30 \cdot 10^{-18}$ m^2. Comparison of the data obtained for the Itatsky and Kamenny sites shows that mean permeability value for first one is three times higher ($1.92 \cdot 10^{-19}$ m^2) than mean permeability of the samples collected from the site Mars-2, PA Mayak. Mean permeability of the samples from the Kamenny is much more higher: by one decimal order ($1.98 \cdot 10^{-18}$ m^2), significant parameter variations are also proper for this site. The trends of permeability increase with depth are typical for both wells (fig. 3a).

So, the mean porosity values for metavolcanites from the Mars-2 site and granidoids from the the Itatsky and Kamenny sites are very close (the difference is only ~ 0.1 %). At the same time mean permeability of granitoids is significantly (one decimal order) higher then of metavolcanites. In [*Petrov et al.,* 2005 a, b] it were shown than during the geological history metavolcanites and granitoids both were exposed to numerous alterations, which frequently lead to second porosity initiation. However higher degree of such alterations is proper to granitoids. The results of microstructure studies reviled that permeability of tight, low porous rock is caused by microcracks [*Zharikov et al.,* 1993]. Microcrack density in granitoids which refer to britle low-rigid type of petrophysical media is significantly higher then in metavolcanites of viscous rigid type [*Laverov et al.,* 2001, *Starostin*, 1988]. As a result mean permeability in granitods is significantly higher then in metavolcanites. However such permeability values are low enough to believe both considered types of rocks as safe media for location of HLW-SFN repositories or depositories if they will be placed in blocks of intact rocks which thickness will be enough.

Permeability behavior under heating (fig. 2, 4) is also controlled by rock microstructure effect. In the initial samples of metavolcanites microcrack density is not high. As a result generation of new microcraks located to mineral boundaries leads to rock permeability increase. In contrast, there are many microcrack of significant length and apertures in the granitoid initial samples. Such microcracks are not stables, so heating firstly may lead to permeability decrease. Subsequent temperature increase may lead permeability decrease within whole temperature range, or inversions on temperature permeability trends may appear: permeability decrease may be changed by parameter increase. It should be noted that even under conditions when parameter values are minimal and close to ones proper to matrix rock permeability in anisotropic rocks survive stables fluid paths at microscale: through oriented mickrocracks along rock schistosity.



a b

Fig.5. The models of well HLW repositories presented by a single well (a) and a cluster of wells (b).

In order to determine the dimensions of intact rock blocks which insure safe HLW and SNF disposal numerical simulation of free thermal convection of underground water arising in the rock massive where a repository is located was carried out. Theoretical basis of the used technique was described in details in [*Malkovsky et al.,* 1998], where a model of repository presented by a single vertical well which bottom part is loaded by the containers with heat-generating HLW (fig. 5 a) was considered. The object of simulation was to estimate the transport of the most dangerous radionuclide - ^{90}Sr by ground water from the repository to biosphere. ^{90}Sr concentration in near surface water was calculated with respect to repository depth, its shape, porosity and permeability of host rocks, thermophysical properties of rocks and water and HLW heat-generation. Such depth (a distance between earth surface and loaded well part – z_1,, see fig 5 a) of HLW well repository was classified as safe if ^{90}Sr concentration in near surface waters does not exceed its maximum permissible concentration. Key parameters of underground media were determined using the values characterizing low fractured crystalline rocks which compose the sections of Itatsky and Kamenny sites of Nizhnekansky massive [*Petrov et al.,* 2005 a]. So, the results of physical modeling were used as input data for numerical simulation. Computer simulation allowed also to determine the horizontal extent of intact rock blocks for safe HLW disposal [*Malkovsky & Pek,* 2007]. The estimations were based on the simulation of the radionulide transport by thermal convection in cases of single well and a cluster of wells loaded by waste in their bottom parts with respect of HLW and rock physical properties as well . Thereby not only the horizontal extent of intact rock block in case of single well but the distance between the wells in case of cluster of wells were determined (*L*, see fig. 5 b).

Summary

The results of transport properties of tight rocks studies, their interpretation and use for search of the area for safe underground deposition or reposition of HLW and SNF on the basis of the data of physical and numerical experiments were considered. The rock samples collected from the sites of probable location of HLW and SNF depositories or repositories: metavolcanites from the area of PA Mayak. and granitoids from the Krasnoyarsk MCC zone were used for the laboratory study. On the basis of the comparative analysis of the experimental data and the results of microstructure studies the main factors controlling rock transport properties were found. A forecast of permeability changes under heating due to HLW heat-generation was done. Use of the results of physical experiments as input data for numerical one allowed to determine intact rock thicknesses which are enough for safe location of HLW depositories.

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