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Mechanics

Estimation of Physical Properties of Rocks for Metro Ventilation

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ABSTRACT. **The outcomes of this study provide new experimental information that contributes to improve the understanding of thermo-physical and mass-physical properties of rocks in the characteristic ranges of physical fields for the temperature 275-323K and the moisture content 2-12%. Results indicate that thermo-physical properties are constants in the above mentioned ranges. Mass-physical properties, on the contrary, change their numerical values for the same ranges by 300% and more. Therefore, to perform thermo-physical estimation of the ventilation of the metro, it is necessary to consider only the change in mass-physical properties. Thermo-physical properties must be considered as constants.** *© 2019 Bull. Georg. Natl. Acad. Sci.*

Key words: ventilation, thermal-physics calculation, thermo- and mass-physics characteristics

Simultaneous processes of heat and mass conductivity take place in the surrounding mining massif of transport tunnels, which is the result of heat and mass transfer between ventilation flow and the massif. Natural physical fields of the temperature and mass transfer potential in the massif undergo significant changes over time and the processes are clearly non-stationary. Consequently, the performance of thermal-physics calculations is significantly complicated and requires presence of both nature of changes in the physical properties of rocks and nature of changes in the fields.

Based on the foregoing, we studied physical characteristics for certain ranges of changes in the physical fields: temperature and moisture content of the massif, choice of which is due to the practice of operating transport tunnels. In the present paper the mentioned physical fields are: the temperature field of the mining massif in the range of 275-323K and the moisture content field in the range of 2-12%.

Despite the non-stationarity of the heat and mass transfer processes, the thermo-physical properties in the present work are mainly considered as constants for the mentioned characteristic temperature and mass transfer potential fields in the massif of the underground structures [1-3]. The mass-physical properties of rocks strongly depend on fluctuations of the mentioned physical fields, which is the subject of consideration of the present paper.

The outcomes of study provide new experimental information that contributes to improve the understanding of thermo-physical and mass-physical properties of rocks in the characteristic ranges of physical fields: temperature 275-323K and 2-12% the moisture content.

Materials and Methods

Mass-physical characteristics of rocks were studied at different temperatures. Four temperatures 275, 289, 303 and 323K were chosen taking into account the geothermal conditions around the underground metro space. For all rock samples isotherms of sorption and desorption with water vapor were constructed.

In the case of tunnels ventilation, the thermal exchange in a binary system "mining massif – ventilation flow" occurs not only under the influence of the temperature gradient but also of the mass transfer potential gradient. The final thermal flow consists of two elements: one is caused by the temperature gradient and the second – by the mass transfer potential gradient. So, for the final thermal flow: the temperature gradient is the direct driving force and the mass transfer potential gradient – an indirect driving force. Similarly, the final mass flow also consists of two elements. In this case, the gradient of mass transfer potential is the direct driving force and the temperature gradient – the indirect driving force. This is reflected in the mathematical expression of the principle of Onsager reciprocity [4] that expresses the equality of certain ratios between flows and forces in non-equilibrium thermodynamic systems

$$J_i = \sum_{k=1}^{n} L_{ik} X_{k(i=1,2,\ldots,n)} , \tag{1}$$

where J_i is the thermal or mass flows; L_{ik} – the properties of the physical environment in which energy or substance is transmitted (in our case the thermo- and mass-physical characteristics of rocks); X_k – the potential gradients, by means of which thermal and mass flows are originated.

For the thermodynamic driving forces, such as the temperature gradient and the mass transfer potential gradient, the principle of Onsager reciprocity has a form

$$J_1 = L_{11}X_1 + L_{12}X_2, \tag{2}$$

$$J_2 = L_{21}X_1 + L_{22}X_2, \tag{3}$$

where J_1 is thermal flow density, which is determined by the Fourier law in the private case; J_2 – the density of mass flow, which is determined by the Fick's law or a Luykov law in the private case in accordance to the nature of this driving force.

In a continuous medium there are no pores and the mass transfer does not take place, i.e. $X_2 = 0$ and formula (2) gives the Fourier law

$$q = -\lambda gradT, \tag{4}$$

where $J_1 = q$ – the thermal flow density, J/(m^2.s).

Thus, for the process of thermal conductivity, physical parameter L_{11} from formula (2) is the heat conductivity coefficient of the rock λ .

Similarly, during the isothermal mass transfer in the capillary-porous mining massif, when the temperature gradient is equal to zero, i.e. X_1=0 and mass transfer occurs only by means of mass transfer potential, formula (3) gives the Luykov law [5]

$$q_m = -\lambda_m grad\theta, \tag{5}$$

where $J_2 = q_m$ is the mass flow density, kg.mol/(J.m^2.s); $grad\theta$ – the gradient of mass transfer potential, J/(mol.m).

F formula (5) also takes the following form

$$q_m = -a_m c_m \gamma_0 grad\theta. \tag{6}$$

Results and Discussion

Determination of the diffusivity factor of mass transfer potential for rock (a_m). Formulas (3) and (6) indicate that to determine mass-physical characteristics, in particular, the diffusivity factor the protection of the isothermal conditions in mass transfer processes is necessary. It is possible in special laboratory device, in isothermal container. For the purpose of solving the set tasks, the samples were crushed and sieved to fraction 0.25 mm, moistened and then molded in the cylindrical containers together with completely dry filter paper. The time for observation of containers at temperatures 275, 289, 303 and 323K was 48-72 hours.

During this time the thermodynamic equilibrium was established in the boundary layers of the above-mentioned bodies – the chopped and sieved rock simple and filter paper. In order to control the results, observations were conducted on three containers at the same time, and parallel samples from each container were taken. Thus, each value of the coefficient is actually the average of six measurements.

With the help of the parameters and computational values obtained by the experiment, the diffusivity factor of mass transfer potential will be defined with the following formula:

$$a_m = \frac{\pi}{\tau}\left[\frac{\Delta M}{2S\gamma_0(U_0 - U_1)}\right], \tag{7}$$

where τ is the duration of experiments, 48-72 h; ΔM – a mass difference of sample before and after testing, kg; S – the container area, m^2; γ_0 – the density of absolutely dry sample, kg/m^3; U_0 – the initial sample moisture, kg/kg; U_1 – the moisture content of sample in the border zone, kg/kg.

The results of the experiments are shown in Fig.1.

Determination of the isothermal factor of specific mass (c_m). In laboratory conditions, for all samples of rocks the isotherms $U = f(\varphi)_T$ of sorption and desorption for four temperatures: 275, 289, 303, 323K were constructed (Fig. 2).

On the basis of the results new curves $U = f(\theta)$ were constructed and the potential of mass transfer was calculated using formula

$$\theta_0 = R(273 + t_0)\ln\frac{U_0}{U_{\max}}, \tag{8}$$

where R is an universal constant of gas, J/(mol.K), R = 8.3144; $(273 + t_0)$ – the temperature of rocks sample; U_0 – an initial or natural moisture content of rocks sample; $U_{\max}$ – a maximal sorption moisture content of rocks sample.

By means of mass transfer potential calculated according to formula (8) the new curves $\theta = f(U)_T$ were constructed. By the method of graphic differentiation from the latter isotherms the coefficient of isothermal specific moisture was determined from the ratio

$$c_m = \frac{\partial U}{\partial \theta}. \tag{9}$$

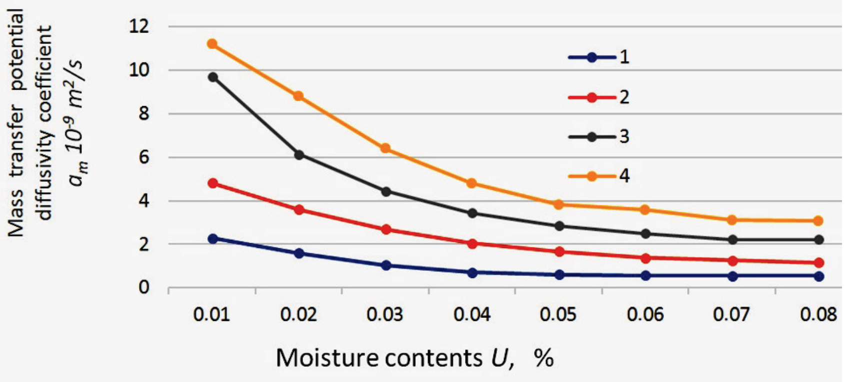

Fig. 1. The change of the diffusivity factor of mass transfer potential of the rock sample (a_m, 10^{-9} m^2/s) on moisture content at temperatures, K: 1 – 275; 2 – 289; 3 – 303; 4 – 323. Results are given for the sample of lime sandstone.

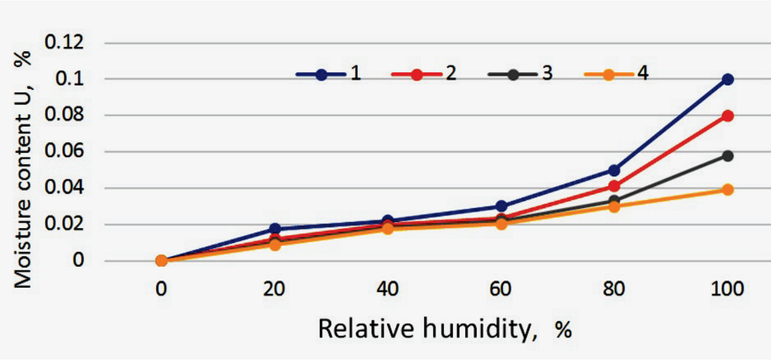

Fig. 2. Sorption isotherms of the rock sample to water vapor at temperatures, *K*: 1 - 275, 2 - 289, 3 - 303, 4 - 323. Results are given for the sample of limestone sandstone.

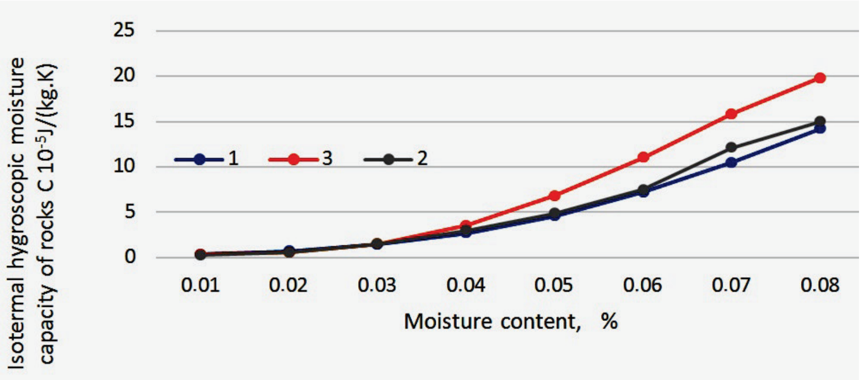

Fig. 3. Change of the isothermal specific moisture (c_m, 10^{-5} mol/J) depending on the moisture content and temperature of rocks, *K*: 1 - 275, 2 - 289, 3 - 303. Results are given for the sample of lime sandstone.

Change of numerical values of the isothermal specific moisture for the rock (c_m) obtained by the experiments is given in Fig. 3.

In the isothermal conditions this coefficient (c_m) is directly proportional to the mass transfer potential defined by formula (8). On the other hand, when the mass transfer potential is constant in time, above mentioned coefficient has inverse proportion with the absolute temperature, which is in accordance to the modern theoretical ideas about reduction sorption forces of Van der Waals by the temperature increasing.

For thermodynamic potential (known from the course of thermodynamics as a chemical potential μ) this coefficient (c_m) has an inverse proportion attitude, which is determined by the structure of the calculation formula ($\mu = -RT\ln\varphi$). If this fact did not contain theoretical discrepancy, then it could be impossible to justify the direction of proportionality between coefficient c_m and mass transfer potential μ.

The matter is that temperature increase leads to reduction of Van der Waals forces in the field of sorption forces mentioned above as the result of which the coefficient c_m is reduced. In this case the power of sorption field and the characteristic size of this field, the potential of mass transfer, must be reduced. Consequently, between the couples θ, T and c_m, T proportion dependence should be inverse while between θ and c_m it should be direct proportional relation. This circumstance does not contain any contradictions between theoretical ideas and experimental results of determining coefficient of the isothermal specific moisture. Therefore, the present paper uses the potential of mass transfer, defined by formula (8).

It should also be noted that numerical values of the present results were determined on the basis of increment of the mass transfer potential, and not for its absolute number, therefore, the sign of the potential does not have any sense on the application of the physical properties, presented here.

Conclusions

Thermo-physical and mass-physical characteristics of rocks in different physical fields undergo changes that should be considered by thermal physics calculations practice. For some purposes the calculations of tunnel ventilation can be assumed that thermo-physical properties of the rocks are constants in the temperature range of 275-323 *K* and in moisture content range of 2-12%. For the mentioned intervals, mass-physical properties change to 300% or more, which indicates that for thermo-physical calculation of the ventilation of the metro it is necessary to consider only the change in mass-physical properties. Thermo-physical properties should be considered as constants.

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მექანიკა

ქანების ფიზიკური თვისებების განსაზღვრა მეტროს ვენტილაციისთვის

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მეტროს გვირაბების სავენტილაციო ჰაერსა და გარშემომცველ სამთო მასივს შორის მიმდინარეობს ერთობლივი სითბოსა და ჰიგროსკოპული მასის გაცვლის პროცესი. ქანების თბოფიზიკური და მასაფიზიკური თვისებები, ისე როგორც ტემპერატურისა და მასაგადატანის პოტენციალის ველები განიცდის ცვალებადობას და ურთიერთგავლენას გარშემომცველ სამთო მასივში. ნაშრომში აღნიშნული საკითხი განხილულია ონზაგერის ნაცვალგების პრინციპის გამოყენებით. სატრანსპორტო გვირაბების ირგვლივ სამთო მასივში დამახასიათებელი ფიზიკური ველების ცვალებადობის დიაპაზონები წინამდებარე ნაშრომის ინტერესებიდან გამომდინარე შეადგენს: 275-323 *K* ტემპერატურის ველისათვის და 2-12% ტენშემცველობის ველისათვის. შესრულებული ექსპერიმენტული კვლევების საფუძველზე უნდა აღინიშნოს, რომ ქანების თბოფიზიკური მახასიათებლები შესაძლებელია მივიჩნიოთ კონსტანტებად ცვალებადობის მითითებული ფარგლებისათვის. მასაფიზიკური თვისებები კი პირიქით,

იცვლება ტემპერატურისა და ტენშემცველობის ველების ცვალებადობის მითითებული ფარგლებისათვის 300%-ით და მეტით, რაც მიუთითებს მასაფიზიკური პროცესების არაწრფივ ხასიათზე მეტროს მიწისქვეშა ნაგებობებში. მოცემული შედეგები აგრეთვე მიუთითებს, რომ გამოვლენილი ახალი კანონზომიერებების მიხედვით უნდა მოხდეს ანალოგიური ობიექტების თბოფიზიკური გაანგარიშება. სტატიაში მოცემულია ქანების თბო- და მასაფიზიკური თვისებების ცვალებადობის მაჩვენებელი ცხრილები და გრაფიკები ტემპერატურისა და მასაგადატანის პოტენციალის ფიზიკური ველების მიხედვით გარშემომცველ სამთო მასივში.

REFERENCES

1. Jones M.Q.W. (2015) Thermo-physical properties of rocks from the Bushveld complex. *Journal of the Southern African Institute of Mining and Metallurgy,* **115**: 16-30.
2. Hartlieb P., Toifl M., Kuchar F., Meisels R., Antretter T. (2016) Thermo-physical properties of selected hard rocks and their relation to microwave-assisted comminution. *Minerals Engineering,* **91**: 34-41.
3. Petrilean D.C., Stanilă S., Dosa I. (2017) A mathematical model for the determination of the dimensionless heat flux with application in mine environment. *Environmental Engineering and Management Journal*, **16**(6): 1331-1341.
4. Onsager L. (1931) Reciprocal relations in irreversible processes. *Phys. Rev.,* **37**: 405-426.
5. Luikov A.V. (1978) Teplomassoobmen (Reference book), M. (in Russian).

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