THE USE OF THE HOT-BALL METHOD FOR OBSERVATION OF MOISTURE IN POROUS

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Abstract

Influence of moisture on materials leads to changes of physical and chemical properties. Materials with different porosities saturate by various mechanisms. This paper is focused on water transport or diffusion in various porous structures. The Hot-ball method is used for determination of the water content in the certain place of specimen. Process of water transport or water diffusion is closely related to porous structure. Porosity affects transport properties of the material and it is necessary to know the way and mechanism distributing the water in materials with different porosities. Measurements were carried out by thermal conductivity sensors (Hot-ball sensor) located in different positions along path of water movement. Principle of Hot-ball sensor (thermal conductivity sensor) is based on Hot-ball method for measuring thermal conductivity. Local moisture content in porous stone is inspected using Hot-ball method, where the measured values of thermal conductivity are correlated to the water content. Experimental set up for investigation of water diffusion in stones is described.

Keywords: thermal conductivity, moisture, water diffusion, thermal conductivity method, porous materials

1. Introduction

The knowledge of transport of moisture in porous building materials is basic for the estimation of long term performance of buildings and is strongly dependent on the climatic conditions [1]. The mechanism of fluid flow inside the pores is complicated due to the presence of various phases and their interactions with the solid rock matrix. In order to fully understand the transport mechanisms at this scale, one needs to have a better picture of the actual porous structure of rock [2].

The transport in pores is not possible to describe by simple analytical equations. Currently mathematical models include boundary and initial conditions that describes the experiment. Then the mathematical formulation of mass transfer at the macroscopic level in porous media is usually based on diffusion equations. If gravity is neglected, the moisture transport for the one-dimensional isothermal problems that will be considered here can be described by a non-linear diffusion equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}(D_\theta \frac{\partial \theta}{\partial x}) \tag{1}$$

In this equation θ [m^3m^{-3}] is the volumetric moisture content and D_θ [m^2s^{-1}] the moisture diffusivity. In this diffusion model all mechanisms for moisture transport, i.e., liquid flow and vapor diffusion, are combined into single moisture diffusivity, which is dependent on the actual moisture content. The moisture diffusivity D_θ has to be determined experimentally for the porous medium of interest [2].

Experimental studies are focused on determining the moisture content in the certain area of material around sensors to determine the laws by which spread of moisture. The transport in porous structures cannot be described by simple analytical equations. To determine the characteristics of moisture transfer it is necessary to know humidity of the ambient air.

Measurement of thermophysical properties consists of the evaluation of thermal conductivity, thermal diffusivity and specific heat and it provides insight into the optimal selection of a material. Determination of thermophysical parameters of materials has two parts. In the first, heat equation is solved for given boundary and initial conditions and due to solution we get a temperature function, which describes the temperature distribution in the sample. Temperature function includes parameters as time and parameters characterizing the thermophysical properties of the material. In the second part, the experiment is realised that allows determination of the temperature field of a specimen. Then we can calculate the thermophysical parameters from the temperature function and experimental data [3].

2. Principle of experimental method

There are many experimental methods for measuring thermophysical parameters. Transient methods are based on the generation of the dynamic temperature field inside the sample. The measuring process can be described as follows: first, the temperature of the sample is stabilized and uniform; then a small disturbance is applied to the sample by use of a heat pulse, or by use of a heat flux in the form of a step-wise function. From the parameters of the temperature response to this small disturbance the thermophysical parameters can be calculated, according to the model used. In practice, the temperature response is up to 10 K (Fig. 1). We use the transient method based on the hot-ball method (thermal conductivity method).

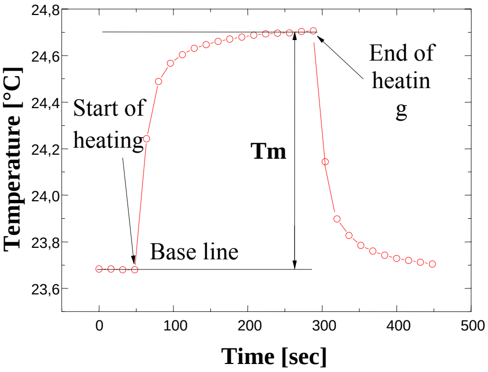

Fig. 1 *The temperature response for constant production of heat*

The sensor is made of two components of a thermometer and a resistance (patented).

The diameter of the finished sensor is in the range of 2 to 2.3 mm (Fig. 2).

The working equation of the Hot-ball sensor is based on an ideal model which assumes a constant heat flux F per surface unit from the empty sphere of radius r_b into the infinitive medium for times $t > 0$. Then the temperature distribution within the medium is characterized by the function [3]:

Fig. 2 *Sensor compared with a match*

$$T(t,r_b) = T_0\left\{1-\exp(u^2)\Theta^*(u)\right\} \tag{1}$$

where $T_0 = \frac{q}{4\pi r_b \lambda}$, $u = \frac{\sqrt{at}}{r_b}$

λ is thermal conductivity and a is thermal diffusivity. $\Theta^*(u)$ is the complementary error function. Function (1) can be derived from the partial differential equation governing heat conduction, considering the initial condition $T(0,r)=0$ and the boundary condition $-\lambda \frac{\partial T}{\partial r}\Big|_{r=r_0} = ql(t)$. For time tending to infinity, $t \to \infty$ equation (1) reduces to its steady-state form:

$$T_m = \frac{q}{4\pi\, r_0 \lambda} \tag{2}$$

Rearranging the latter equation one obtains the working equation of the hot-ball sensor [3]:

$$\lambda = \frac{q}{4\pi\, r_0 T_m} \tag{3}$$

Two evaluation strategies can be applied for signal shown in Figure 2, namely fitting of the function (1) over the temperature response measured in experiment or use of working equation (3) for enough long measuring times.

3. Experiment and results

For the experiments sandstones with 16.96%, 9.06% and 5.9% total porosities were used. Hot-ball sensors (thermal conductivity sensors) in certain positions in the sample are fixed along the saturation path. The samples of sandstone were dried under vacuum and moisturized to water saturated state for calculate its moisture content. The same initial conditions for all samples were established. The specimen was fixed in specimen holder in vertical position and inserted into the climatic device. The temperature of 25 °C and ambient humidity 30% was kept during experiment.

One-dimensional transport process under isothermal climatic conditions was realized from bottom to top of sample. A special mechanism was used to keep a constant water level in about 2 mm locally the bottom of sample. Three Hot-ball sensors were used to determine the quantitative amount of vapour and liquid water (moisture content) in the immediate vicinity of sandstone.

Experimental data obtained from Hot-ball sensors are shown in Fig. 3. Gradual saturation of the specimen depending on the position of Hot-ball sensors can be found. Saturation strongly depends on of porosity. A complete picture about the processes of saturation water in the material with certain porosity can be obtained after saturation. Then the values q/Tm (ratio of the constant output power to change of the temperature during a measuring cycle) are converted to percentage increase of the moisture in the specimen. Moisture content is converted from values q/Tm in this experiment by linear function. Figure 3 shows the local values (arbitrary units) for sensor which is the closest to container with water. This value is plotted in dependence on time. Simultaneously value obtained by weighting whole sample is plotted as a function of time (red dots in graph). The experiment shows that we are able to describe not only the increase of moisture by weight, but by using the Hot-ball method also the local value in some certain place of sample. In fact it is able to determine the thermal conductivity of the specimen in a certain position. Hot-ball sensors were in all three specimens at the same positions. The graphs in figure 3 represent the transport of water from the bottom sensors which are closest to the additional water. Histograms in figure 4 describe distribution pore size in normalized volume obtained by Hg-porosimetry.

For the sample with 16.96 % total porosity starts water saturation very fast (Fig. 3 left). This is typical for materials which contain larger pores which we can see in the graphs in figure 4

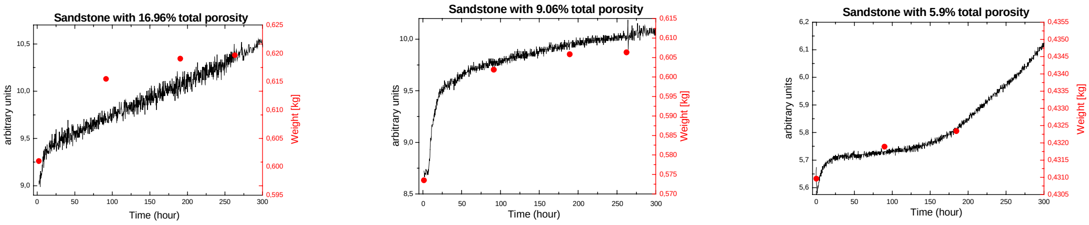

Fig. 3 *Start of saturation in sandstone with different porosity*

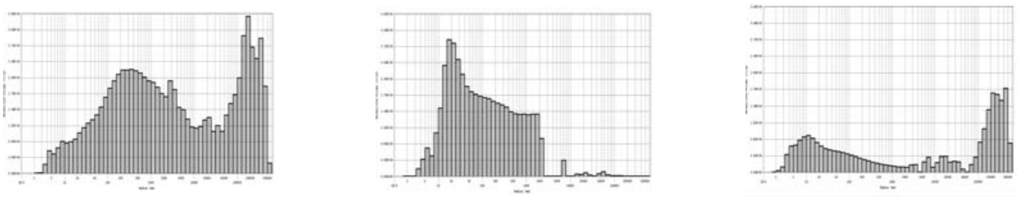

Fig. 4 *Histogram of pores size vs. normalized volume*

left. Sandstone with 16.96% representing pores with 200-500 nm and then has very much pores with size about 200 μm. In materials with very large water saturation is very fast, but it´s only free saturation not capillary saturation.

In the sandstone with 9.06% total porosity (Fig. 4 middle) running water saturation fast course too. Therefore this sandstone has large representation pores with about 15 nm in which running capillary water saturation very rapidly. It can see in the course of saturation curve with longer capillary part of curve (at the beginning of saturation in fig. 3 middle). Capillaries (pores) in such materials are narrow and a high capillary pressure should exist for such materials. In agreement with figure 1 one can see that the radius of capillary *r* is smaller, the water increase is higher.

The sample with 5.9% total porosity represents either pores about 200 μm or about 10 nm (Fig. 4 right). The water saturation is progressive, because at first running filling the bigger pores by water and then the smallest (Fig. 3 right). This corresponds to very low-porous materials where boundary conditions play any role in the transport of water in the sample**.**

The Hot-ball method together with the RTM devices is working independent on the operator and this method is very advantageous for continuous monitoring of moisture changes in rock massive and in historical monuments and for other applications (monitoring of concrete setting, monitoring of polymerization, monitoring of structure transformation in pores, material ageing). Experiments have shown that porosity and structure of materials strongly affects the process and behavior of water saturation.

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