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One-dimensional moisture transport monitored by a non-destructive method

Jan Skramlik and Miloslav Novotny

***Abstract*—**Moisture in building structures influences the physical properties of materials and can cause their degradation. Apart from few exceptions, building materials are hardly dry every time. They always contain some moisture within the solid, in liquid or gaseous state. Moisture is of variable quality with different effects on thermal and technical properties. To express an anticipated negative effect of moisture on building materials related to building structures it is necessary to achieve an accurate way of determining their moisture characteristics if possible.

***Keywords*—**moisture, capillary conductivity, non-destructive, humidity by weight, porous material, moisture transport, humidity profiles.

I. Introduction

A prevailing type of realized wall building structures is masonry construction from block building materials bonded with mortar. A considerable number of building failures are caused and accompanied by undesirable influences of moisture.

Contemporary trends in the building industry lay high demands on failure-free functioning of buildings, especially on thermal insulation qualities of their envelopes. Up to now insufficient amount of attention has been paid to material properties of porous building materials and specification of their characteristic humidity parameters. A necessary quantity for their expression is the coefficient of moisture capillary conductivity κ.

II. Input Data for Calculation of the Coefficient of Capillary Conductivity

A non-destructive method using microwaves was chosen in order to validate outputs that serve for determining the coefficient of capillary conductivity. If we know the spatial and temporal distribution of moisture in a given material, we can establish the coefficient of capillary conductivity κ (1). At present Matan's method is used in the case where a boundary condition is not applied at the dry end of a sample as a method for non-stationary moistening in combination with the gravimetric method. We can use this provided method with the fact that we know one wetting curve and the time interval corresponding to the curve in order to verify the possibility of obtained outputs of experimental measurements by means of microwaves without destruction of the explored sample. In comparison with the gravimetric method, determining moisture distribution using electromagnetic microwave radiation (hereafter EMWR) provides continuous measurement of necessary data together with elimination of inaccuracies due to the human error and measurement of more wetting curves in one sample, which allows for using other calculation methods as well.

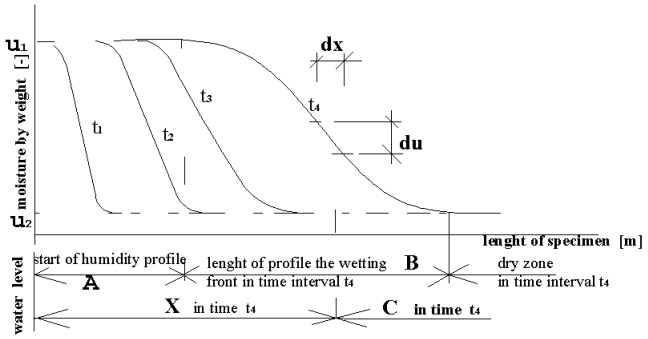

Fig.1 Humidity profiles $u(x)$ at time intervals t_x

Fig. 1 shows a theoretical assumption of the course of wetting curves at time intervals from t_1 to t_4 following the start of moistening as well as boundary conditions needed for calculation of the coefficient of moisture conductivity κ.

Lengths as coordinates are marked along the x axis, at the distance from the contact of the measured sample with the free water level:

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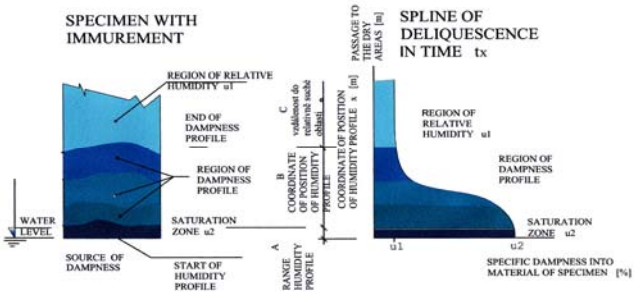

Fig.2 Humidity profiles $u(x)$ at time intervals t_x in moistening of measured sample with marked initial and boundary conditions for determining the coefficient of capillary conductivity

A is the starting coordinate of the profile of the wetting front, B is the length of the wet section, and C is the dimension into the dry region → ∞. Along the vertical axis are plotted the values of humidity by weight, where u_2 is humidity by weight in the measured sample and u_1 is humidity by weight in the measured sample after its moistening.

The experiment simulates real masonry deliquescence. The sample material is placed in the measuring apparatus, which's arrangement is based on approximation of one-dimensional water flow [7]:

$$q = -\rho_S . \kappa_m . \nabla u = -\rho_S . \kappa . \frac{\partial u}{\partial r} \quad [\mathrm{kg.m^{-2}.s^{-1}}] \qquad (1)$$

where
q is vector of density flux of capillary water [$kg \cdot m^{-2} \cdot s^{-1}$]
$\partial u/\partial x$ is gradient of humidity [m^{-1}]
ρ_s is density of the sample in the dry state [$kg.m^{-3}$]
u is humidity by weight [-]

By combining the Lykov's equation, which is a phenomenological description of liquid moisture transport in porous materials, and the continuity equation, whose general form is:

$$\rho_S . \frac{\partial u}{\partial t} = \nabla . q = - div\, q \qquad (2)$$

The water transport is also always determined by the moisture gradient [7] which expresses the classic conservation of matter principle that liquid moisture in a given elementary volume decreased during an elementary time interval by the quantity of liquid, which is drained during the interval through the closed surface enclosing this volume. Thus we obtain a non-linear diffusion type equation , which plays a principal role in describing moisture transport in capillary porous materials under isothermal conditions [7]:

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x} . \left(\kappa . \frac{\partial u}{\partial x} \right) \qquad (3)$$

If we arrange the measurements in such a way that the liquid can rise through the sample only in the direction of the x axis, and in the directions of the axes z and y, parallel with the water level, and the humidity gradients are equal to zero, then the last equation can be expressed in one-dimensional form[8]:

$$\rho_S . \frac{\partial u}{\partial t} = -\nabla . \left(-\rho_S . \kappa . \nabla u \right) \qquad (4)$$

(temporal change in the quantity of liquid water in the material equals the negative spatial change in flow density).

To simplify the calculations, we use Boltzmann's transformation. By gradual rearrangements with the help of Boltzmann's transformation and by converting function u of two variables x, t to function ω of one variable η with boundary conditions $u(0,t) = \omega(0) = u_1$ a $u(x,0) = \omega(\infty) = u_2$ we obtain a common differential equation, which cannot be solved analytically for constant κ(u). However, the numerical solution of the common differential equation is much simpler than the solution of the partial differential equation. So if we arrange the measurements in a way that the liquid can rise through the sample only in the direction of x axis, and in the directions z and y, parallel with the liquid level, humidity gradients are equal to zero, the last equation can be expressed in one-dimensional form [7]:

$$\frac{d}{d\eta} \left(\kappa . (\omega) . \frac{d\omega}{d\eta} \right) + 2 . \eta . \frac{d\omega}{d\eta} = 0 \qquad (5)$$

where ω is humidity as a function of new variable η under the condition that t is a given time interval of deliquescence.

The coefficient of capillary conductivity can be calculated either by gradual integration according to the x coordinate (ξ) or by introducing ξ to substitute the distance measured along the samples length from the point on the curve of the wetting front du, expressed in the formula up to ∞. In practice, however, it is included in the interval on the measured sample up to the distance, where moisture occurs in steady state, i.e. u_2, which is the value of relative humidity in the measured material.

If we know the moisture distribution $u(x)$ in a given time t, (i.e. t is a constant and $u(x)$ is a function of a single variable x), we can express moisture conductivity coefficient κ [8]:

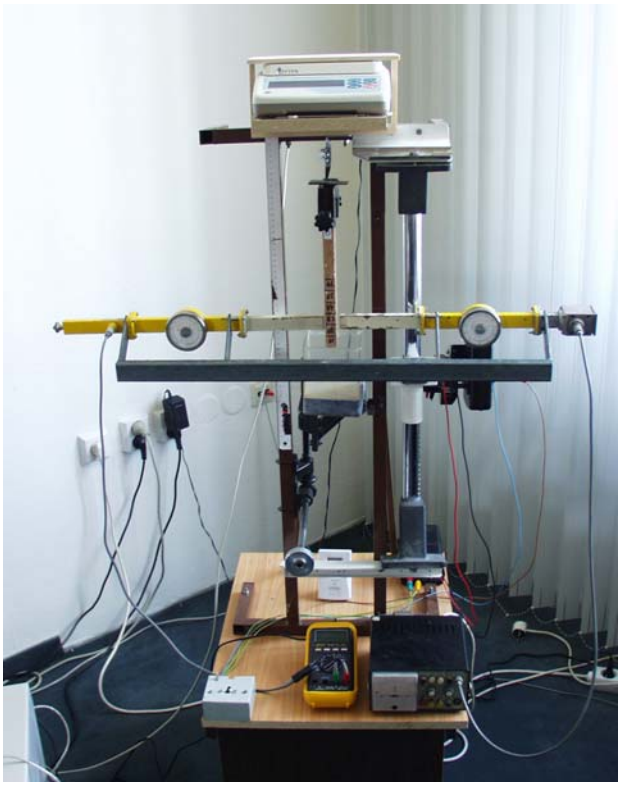

Fig. 3 Construction of experimentally assembled measuring

$$\kappa\left(u\left(x\right)\right) = \frac{1}{2.t.u'\left(x\right)} \int_{x}^{\infty} \varsigma u'\left(\varsigma\right).d\varsigma \qquad (6)$$

where:

κ (u(x)) is capillary conductivity coefficient [$m^2.s^{-1}$]

t time interval, in which humidity is measured as a function of curve $u(x)$ [s]

ς substitution of the distance measured along the sample length from the point on the curve representing wetting front du, expressed in the formula up to the distance

ω new variable, assuming that t is a concrete time interval [-]

η transformation denoted as Boltzmann coordinate [$m.s^{-1/2}$]

x coordinate in the length of sample from the bottom of the measured sample [m]

u_1 maximal value of humidity by weight [-]

u_2 humidity of material by weight in the state of relative humidity [-]

III. Experimental Measurements Using Electromagnetic Microwave Radiation

At the Institute of Building Structures, Brno University of Technology a measuring apparatus was experimentally set up to detect moisture transport in a building material, using EMWR based on theoretical assumptions for expressing input data needed for calculation of capillary conductivity coefficient. The principle of detecting liquid moisture was based on the knowledge of EMWR behaviour in an interaction with various materials.

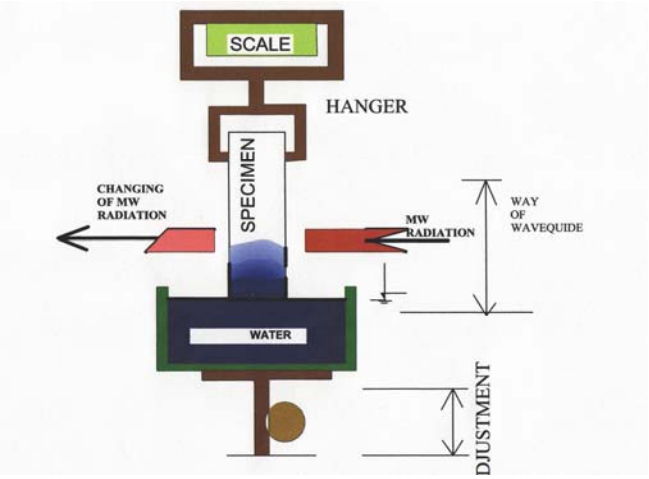

Fig. 4 Detail of experimentally assembled measuring

Fig. 4 represents a detail construction diagram of experimentally assembled apparatus for monitoring moisture transport in porous materials. It is made up of a tank to contain liquid, a positioning mechanism, which serves to vary the level of liquid. The tested sample is placed beneath the tank and it is fastened in a stirrup hanging on a digital scale. In the space above the tank is accommodated a waveguide transmitting microwave radiation, linked to a radiation source (in this case Gunn diode). On the other side of the tank, opposite of the transmitting waveguide is situated a receiving waveguide. Both waveguides, as one unit, are height adjustable and are arranged on a supporting frame (not shown in the figure).

Both waveguides have built-in shutters, by means of which radiation intensity can be regulated. The sample is put between the two ends of waveguides. A microwave receiver is connected to a multimeter, where the values of varying radiation intensity can be read at the output. The multimeter is linked to a computer, where, by means of appropriate software, you can monitor results. They are shown in the form of recorded values of EMWR intensity variations in pre-set time intervals. A communication program serves to transfer indicated quantities, which reads data on the digital scale display. A synchronized power unit for waveguide motion enables conversion of velocity of their shift into units of length to express the x coordinate showing the location of moisture concentration.

A. Interaction of EMWR with wet porous material

Electromagnetic microwave radiation, which penetrates a porous material, is to a small degree absorbed by the solid phase of the given material (including crystal bonded water) and to a large degree by the free, i.e. chemically not bonded moisture, particularly by liquid water in pores. The absorbed energy is in both cases used to overcome the friction forces preventing rotating or deforming molecules in the material from motion. Molecules are forced to move by a variable

electric field of EMWR. The more the molecules in the EMWR variable field can rotate or deform each other and the denser the medium, the greater the friction between the molecules and the medium and more EMWR is absorbed and converted into heat. Molecular chains in the crystal lattice of a porous material practically cannot rotate or deform each other and therefore they nearly do not absorb any EMWR, even if they are highly polarized. Molecular chains on the crystal grain borders (in the inter-crystal phase) can be more deformed and so absorb EMWR (it is the case of poly-crystal materials, it means ceramic, as for instance burnt brick). Polarized molecules of water vapour present in the pores can rotate better in the EMWR field, as well as the water molecules in the liquid phase. Polarized water molecules are in a very dense medium, and therefore liquid water absorbs EMWR most intensively.

Utilization of EMWR for monitoring moisture transport is based on the Lambert-Beer's law that expresses the relation between absorbance, optical length and concentration from the absorbing substance. The empirically derived law itself has the exponential form:

$$A = \log Io/I = k \cdot c \cdot s \quad (7)\ [3]$$

Where:
A is absorbance [-]
I_0 incident radiation intensity
I radiation intensity after passing through the substance
s length of the material, through which the radiation passes optical length [m]
c molar absorptivity (extinction coefficient) [$m^2.mol^{-1}$]
k coefficient of molar concentration of the substance in the solution [$mol.m^{-3}$]

The unit in this case is Bel B (more frequently decibel dB), since decadic logarithms are used, otherwise for natural logarithms it would be Neper Np. This law is based on the presumption that layers of identical, very small thickness ds attenuate the radiation by always the same aliquot part d I, proportional to the layer thickness.

A point-focused beam of electromagnetic microwave radiation 2,4 GHz with flux I_0 penetrates a sample of thickness s = 20 mm and at the opposite side it comes out decreased to the value I. Transmittance t, or absorbance A are defined as the quotient [3]:

$$\frac{dI}{I} = -\alpha.ds$$

or

$$A = \frac{I_0 - I}{I_0} = 1 - t$$

Transmittance depends on the sample thickness. Based on the Lambert-Beer's law you can determine the absorption coefficient α, which is not dependant on its thickness and therefore is the material constant [3]:

$$t = \frac{I}{I_0}$$

from where by integration:

$$I = I_0 . e^{-\alpha.s}$$

Where:
I_0 is boundary intensity in the point s = 0.

According to Beer's law, the coefficient α is directly proportional to the concentration of the material absorbing radiation.

By logarithming the integral law we obtain [3]:

$$a = -\frac{1}{s}.\ln\left(\frac{I}{I_0}\right) \quad (8)$$

Based on the Lambert-Beer's law you can determine the absorption coefficient α, which is not dependant on its thickness and therefore is a material constant [6]. The absorption coefficient α is significant because of its identical value for the same (and equally moist) material of variable thickness and thus it was not necessary to provide samples with a defined thickness. Liquid moisture and to a smaller extent also water vapour, which are present in a sample, decrease transmittance of a sample and increase the absorption coefficient for EMWR..

Liquid moisture and in a smaller degree also water vapour contained in the sample decrease transmittance of microwave radiation t and increase the absorption coefficient α

B. Contribution of moisture to EMWR transmittance

Water and water vapour, whose strongly polarized molecules are not bound in the crystal structure are, conversely, oriented by the cyclically variable electromagnetic field of the radiation (their electric dipoles are rotated against the direction of electric component of radiation), and that is why the radiation and its energy are absorbed. The absorbed energy is used to overcome friction forces that prevent rotating molecules from moving. The denser the medium, the greater the friction between rotating molecules and the medium becomes. That is why liquid water absorbs EMWR much more than water vapour.

A point focused flux of EMWR I_d, represents the voltage output of 500 mV at the output sensor which irradiates a sample of ceramic burnt brick sized 2 x 10 x 20 cm under

conditions of steady moisture. The measured flux after passing through the thinnest wall of the sample drops to the value of 385 mV. Transmittance of a material with a steady humidity then is t = 385/500 = 0.77 and the absorption coefficient according to ( ) is α = 13.07 m^{-1}. Then the total absorption coefficient is :

$$\alpha = \alpha_s + \alpha_v$$

Where:
α_s is the absorption coefficient of a dry sample
α_v is the absorption coefficient of the moisture in the sample [3]

$$t = t_s \,.\, t_v \qquad (9)$$

hence

$$t_v = \frac{t}{t_s}$$

and

$$\alpha_v = \frac{\alpha - \alpha_s}{1 - \alpha_s} \qquad (10)$$

Where:
t_s is transmittance of a dry sample;
t_v is permeability of moisture content in a sample.

For the absorption coefficient of the present moisture applies [3]:

$$\alpha_v = -\frac{1}{s}\left(\ln(t) - \ln(t_s)\right) = -\frac{1}{s}.\ln(t) - \alpha_s \qquad (11)$$

Functional dependence of radiation intensity with its preset value in Fig. 4 expresses a degree of absorption of EMWR on its input intensity when detected in the apparatus units, i.e. mV. Radiation intensity is then expressed in mV at the output from the apparatus. Nonlinearity of the curve testifies of inaccuracy within the apparatus – between the voltage and radiation flux, hence the output (radiation flux unit is W). The graph is suitable for subtracting the contribution of steady moisture from the total absorbance of radiation flux so that we might work only with the absorbance caused by rising water.

The graph in Fig. 5 demonstrates that there is a case of linear dependency between the detected voltage, which represents the input flux of EMWR, and the voltage induced by the intensity of output radiation on the value of preset voltage.

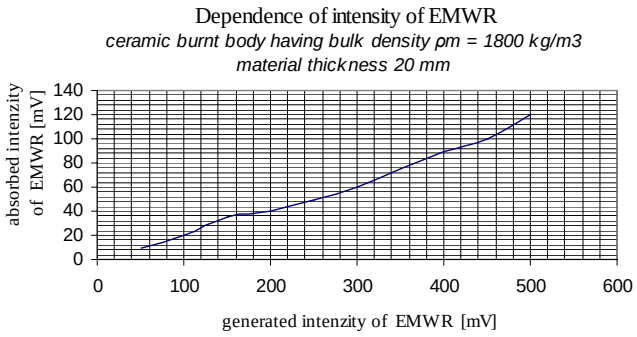

Fig. 5 Difference between the voltage representing the input EMWR flux and the voltage detected in the flux after the passage through the sample subject to the voltage value determining the input flux

Due to the fact that the radiation, which passed through the sample, is directly proportional to the emitted radiation (it applies to low outputs), it is possible to calculate photometric quantities in formulas (9), i.e. absorbance t a transmittance α directly by means of u_{in} and u_{out} from the output of the apparatus:

$$t = \frac{u_{out}}{u_{in}} \qquad (12)$$

$$\alpha = \frac{u_{in} - u_{out}}{u_{in}} \qquad (13)$$

C. Determination of dependence of EMWR absorption on weight moisture

Ceramic burnt brick, used for experimental measurements, can be characterized as a porous inert material. In the first phase of the experiments the EMWR transmittances were measured utilizing identical samples of ceramic burnt brick of thickness s = 2 cm with various moisture content. The radiation flux corresponded to the voltage output of 500 mV at the output of radiation sensor. Immediately after these measurements, real moisture was measured using the gravimetric method. Fig. 6 shows a graphic representation of the functional dependence of absorbed microwave radiation on humidity by weight of the ceramic brick sample for the described experimental arrangement and from it we derive the functional dependence as the power function of the third degree:

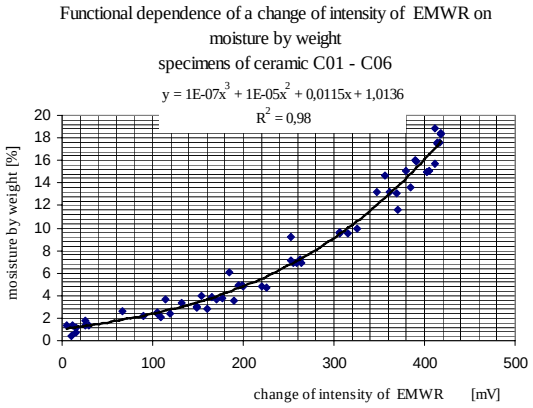

Fig. 6 Functional dependence of a change of intensity of EMWR on moisture by weight for a ceramic burnt body and its conversion in program Maple

$$y(u) = 1.10^{-7}.u^3 + 1.10^{-5}.u^2 + 0{,}0115.x + 1{,}0136 \qquad (14)$$

The origin of horizontal coordinate 0 mV was set according to the level of absorbed radiation for a dry sample, which decreases the incident EMWR flux, represented by the voltage of 500 mV, to the output flux represented by the voltage of 420 mV (a drop by 80 mV; for steady moisture the drop equals to 115 mV – see Fig. 6). Moisture values were determined gravimetrically.

D. Determination of moisture from photometric measurements in the EMWR region

If we replace the voltage as the output apparatus quantity representing EMWR flux and its units mV in equation (16) by a known photometric quantity - transmittance (or alternatively by absorbance) of EMWR in a concrete building material with different moisture content, it can be assumed that results of this work and their interpretations will acquire a certain universality as well as independence of the experimental arrangement. It is based on the results from measurement of ceramic brick shown in the graph in Fig. 7.

A dried sample 0,02 m thick, irradiated by EMWR flux determined by the voltage response of the sensor of the magnitude of 500 mV, absorbs a part of radiation so that at the opposite side of the sample we receive a radiation, which induces voltage response of 420 mV. Transmittance of the sample is:

$$t_s = \frac{u_{out}}{u_{in}} = \frac{423}{500} = 0{,}84$$

Transmittance is dependent on the sample thickness. By applying the formula (11) we can determine the absorption coefficient that already becomes a material property of the sample and is independent of its thickness:

$$\alpha_s = -\frac{1}{0{,}02}.\ln 0{,}846 = 8{,}36 \qquad [\mathrm{m}^{-1}]$$

If the same sample is moistened to 12 % of weight, which according to (16) corresponds to such a drop in EMWR flux after passing though the sample, which in turn corresponds with the drop in the voltage of radiation sensor from 500 mV to 94,33 mV, i.e. by 405,67 mV. Transmittance of a sample with moisture of 12 % of weight for EMWR thus is t = 94,33/500 = 0,189. According to (12) it means that transmittance of water contained in a sample with 2 cm thickness is as follows:

$$t_v = \frac{0{,}189}{0{,}846} = 0{,}223$$

and absorption coefficient according to (11) is

$$\alpha_v = -\frac{1}{0{,}02}.\ln 0{,}223 - 8{,}36 = 75{,}0 \qquad [\mathrm{m}^{-1}]$$

It is obvious that the absorption coefficient of water contained in a sample grows very quickly with its content and it is significant that even lower water content – in the given example 12 % of weight moisture exceeds several times the absorption coefficient of a dry sample.

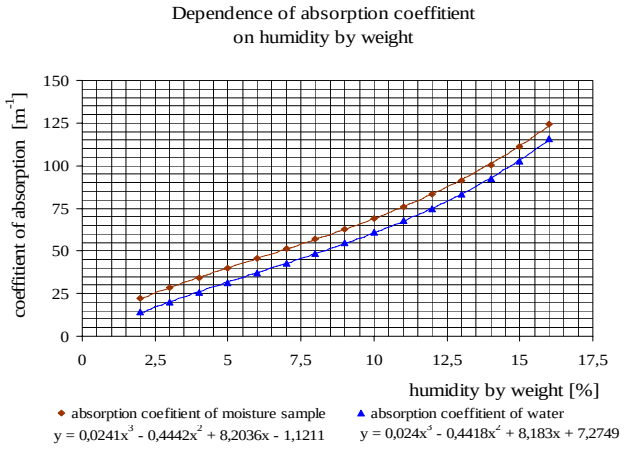

Fig. 6 Dependence of absorption coefficient on humidity by weight

Fig. 5 shows a graphic representation of the dependence of the absorption coefficient of a moistened sample and the absorption coefficient of water contained in the same wet

sample of ceramic burnt brick on its humidity by weight and humidity by volume expressed in %.

Measurements are made using a sample of ceramic burnt brick and it is obvious that the course of dependence of the total absorption coefficient on the weight moisture will be similar for other porous inert materials as well.

It follows from the above-mentioned physical nature of EMWR interaction as well as from the above-mentioned theoretical assumptions that the absorption coefficient of water in relationship (11) can be considered independent of the building material that contains the moisture. In other words, a part by volume water in a sample can be determined directly from the absorption coefficient of water α_v for a building material, which is determined by measuring of transmittance of microwave radiation 2,4 GHz. The course of the absorption coefficient of free water contained in a sample, as expresses by its humidity by volume, should be identical for different types of porous materials.

Fig. 6 show a conversion of the „apparatus“ functional dependence according to equation (16), from the values measured experimentally by means of the experimental microwave apparatus in monitoring a sample of ceramic burnt brick, to more general relations. It can be reasonably assumed that the course of absorption coefficient depending on moisture content will be similar for other materials as well. A part by volume water is here defined as a volume of liquid water contained in the sample divided by the sample volume.

E. Application of EMWR

To detect the location of moisture by weight in a porous structure of an inert material we use properties of EMWR applied to measurement of moisture content by microwave methods. They enable non-destructive measurement; have a relatively high sensitivity and measurement results are not influenced by chemical composition nor by the content of chemically bound water. Microwaves pass through materials without affecting their properties. A suitable frequency for measuring moisture content in porous building materials is about 10^{10} Hz.

Dependence between the quantity of radiation passing through a sample and moisture content in a sample:

The dependence was determined by means of the gravimetric method, which determines moisture in samples by weight and simultaneously the quantity of radiation passing through the sample. Dependence of moisture by weight u on the quantity of radiation z, passing through the sample, is determined from values measured in 6 samples. Fig. 7 presents a measuring graph of functional dependence of a change of intensity of EMWR on moisture by weight for a ceramic burnt brick with bulk density approx. 1800 kg.m^{-3} in the program Maple.

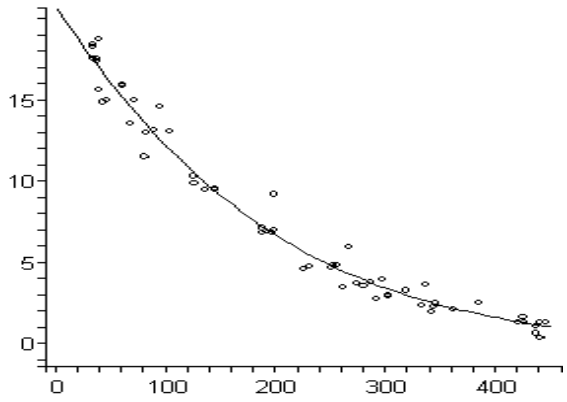

Fig. 7 Functional dependence of a change of intensity of EMWR on moisture by weight for a ceramic burnt body in program Maple

Relationship between the quantity of MW radiation, passing through a sample, and the distance from the source of moisture:

The values of coordinates determining location of the wetting front profile are obtained from measurements using the microwave measuring apparatus. Detection of moisture quantity diffusing in the material is carried out at selected time intervals from the start of moistening of sample material, prepared for monitoring of moisture transport.

Output radiation intensity, depending on the quantity of moisture content, is continuously recorded at preset time intervals by moving waveguides at synchronized velocity along the length of a tested material sample, which is fixed in the stirrup of the hanger on the scale in order to touch the water level.

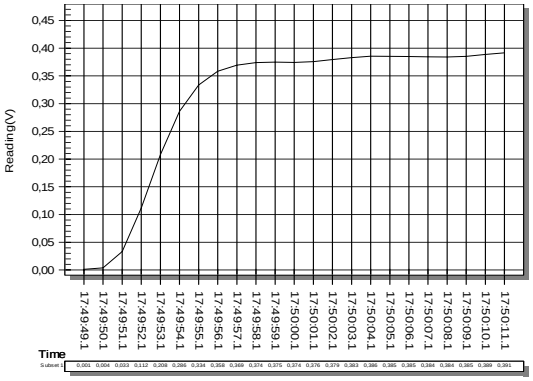

Fig. 8a Initial measured values for determination of location of wetting front profile for brick at time intervals of 10 minutes

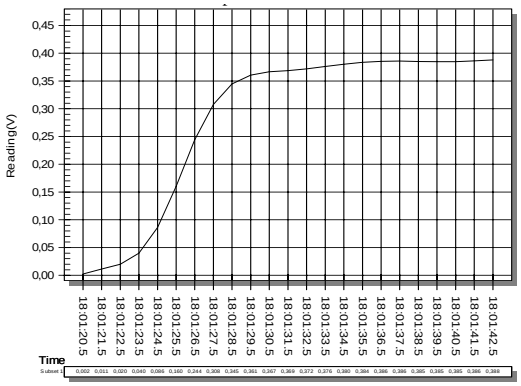

Fig. 8b Initial measured values for determination of location of wetting front profile for brick at time intervals of 20 minutes

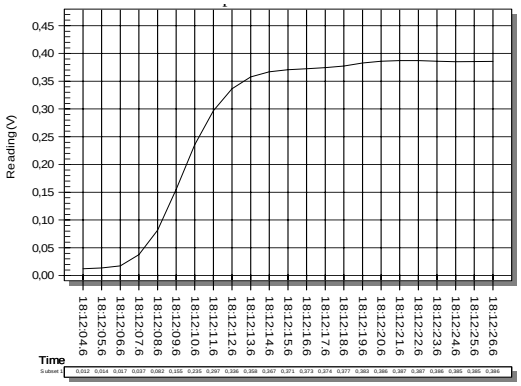

Fig. 8c Initial measured values for determination of location of wetting front profile for brick at time intervals of 30 minutes

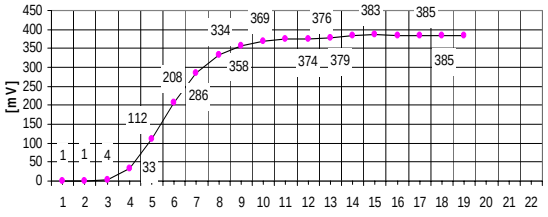

Fig. 9a Conversion of temporal data in compliance with the travel velocity of waveguides to units of length of the X coordinate defining the wetting front profile [mm] for ceramic burnt body at time intervals of 10 minutes using Linregrese Excel

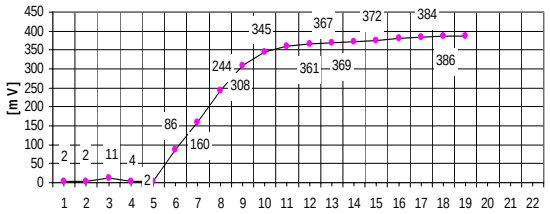

Fig. 9b Conversion of temporal data in compliance with the travel velocity of waveguides to units of length of the X coordinate defining the wetting front profile [mm] for ceramic burnt body at time intervals of 20 minutes using Linregrese Excel

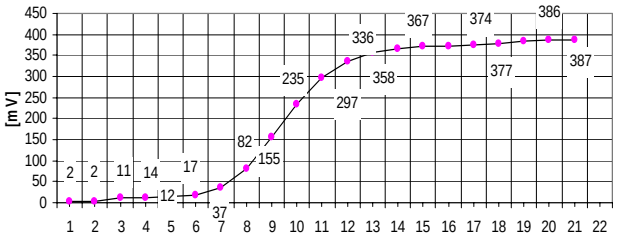

Fig. 9c Conversion of temporal data in compliance with the travel velocity of waveguides to units of length of the X coordinate defining the wetting front profile [mm] for ceramic burnt body at time intervals of 10 minutes using Linregrese Excel

Fig. 9a,b,c shows a conversion of temporal data in compliance with the travel velocity of waveguides to units of length [1 graduation line is 3 mm] of the X coordinate defining the wetting front profile for foam concrete at time intervals of 10, 20 and 30 minutes in Linregrese Excel.

The travel velocity of waveguides is constant and the position coordinates of absorbed EMWR depending the moisture by weight is determined by their conversion to units of length using Linregrese Excel.

These graphs prove that moisture transport can be continuously monitored in the course of moistening of a sample and data on moisture distribution can be recorded at chosen time intervals.

Dependence of EMWR on the location of moisture in the sample material:

Using the method of least squares in the program Maple equations of dependence (see Fig. 10) were determined from the values measured for three different time intervals ((10, 20, 30 min.) from the start of moistening.

The equations describe the dependence of radiation z on the distance from the source of moisture expressed by the x

coordinate, anticipated moistening curves and functional dependence of change in EMWR intensity on moisture by weight u_m and on the length of sample at a chosen time interval of its moistening:

$$z_{10} = 351628808.1x^4 - 44819350.86x^3 + 1664476.757x^2 - 8156.829195x + 2.964486146$$

$$z_{20} = 274311438.3x^4 - 40235433.35x^3 + 1815352.482x^2 - 17809.74743x + 29.24692066$$

$$z_{30} = 621621193.02x^4 - 16736345.45x^3 + 1107438.297x^2 - 14377.52465x + 29.45082869$$

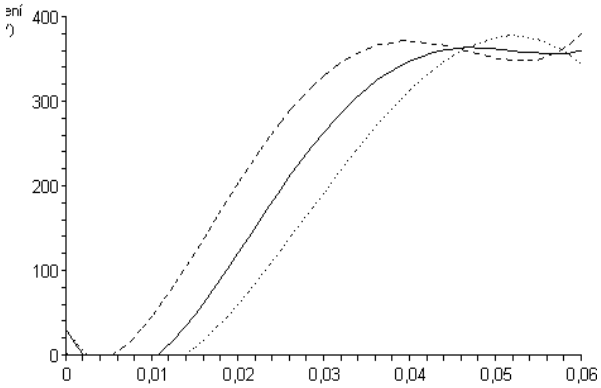

Fig. 10 Expression of change EMWR intensity on the moisture by weight in the length of measured sample (the axis x) at time intervals 10, 20 and 30 min in the course of its moistening (for ceramic brick)

F. Representation of wetting curves

Wetting curves are determined as graphs of complex functions, which are established by combining the functions from previous calculations. Graph plotting of functions expressing dependence of moisture content on the distance from the moisture source.

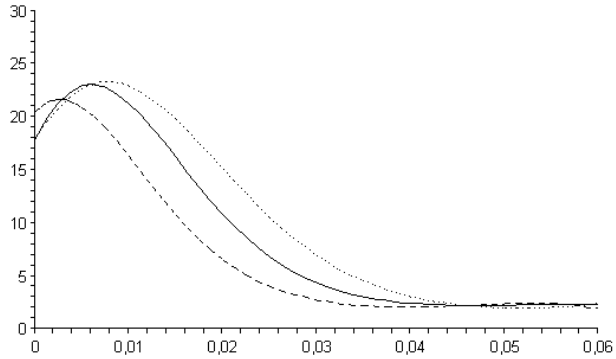

Fig. 11 Wetting curves plotted for ceramic brick

Based on the above mentioned measurements, we are able to express moisture curves (according to the methodology) as a base to calculate capillary conductivity coefficient κ.

IV. Conclusion

The basic theoretical concept for describing moisture transport dynamics in a porous inert material is a combination of the continuity equation with the Lykov's equation, which defines the capillary conductivity coefficient and the relative moisture gradient, acting as a formal driving potential. An easier solution of equation (3), describing one-dimensional moisture transport using Boltzmann transformation results in the fact that a spatial distribution of moisture in the material, which is specified for different periods of time since the start of moistening and leads to the same dependence of capillary conductivity coefficient on humidity by weight. It remains to be verified how exactly the employed model describes real conditions.

The key relationship between moisture of a sample and an apparatus response was established on the basis of measurements of the microwave radiation transmittance in a porous, homogeneous, inert material with a different content of liquid moisture. From the linear characteristics generated by the sensor of EMWR flux of 2.4 GHz in the apparatus, where the sensor output voltage in mV is directly proportional to the beam output in W or the radiation density in W/m^2, it would be possible to determine the transmittance of samples for the radiation and from the thickness of samples to establish the absorption coefficients constants for standard materials, using formulas (9) and (10).

It was found from the measurement of EMWR transmittance in materials with different moisture content that their absorption is significantly dependent on the moisture content in a sample.

This method for calculation of the capillary conductivity coefficient as compared with the gravimetric method offers higher frequency of measurement and accuracy of data on

moisture content in detailed cross sections along the length of tested sample by converting the shift in the direction of longitudinal axis of sample for the measured time interval to sections of the measured coordinate. Values received from continual measurement plotted as curves are suitable for mathematical processing thanks to the measurement accuracy, because the closest possible approximation to the real state is achieved by modelling of the moisture field as well as by calculating the coefficient of capillary conductivity. Detection of EMWR in mV is more accurate in the regions with lower moisture content.

The experimental measuring apparatus and the proposed method of measuring make it possible to continue with mathematical processing of obtained outputs for computing the capillary conductivity coefficient κ.

The advantage is a non-destructive method is the contactless, continuous and relatively fast measurement.

The drawback of this method is the need to determine "calibrating" curves for individual materials, i.e. to determine the dependence of EMWR absorption on the humidity by weight for different building materials.

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