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ABOUT OPERATIONAL FACTOR INFLUENCE ON VAPOR PERMEABILITY OF HEAT-INSULATING MATERIALS

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Abstract

The article analyzes the process of vapor transfer through building materials, taking into account their real operation conditions, the results of vapor permeability characteristic studies for some thermal insulating materials are presented taking into account different temperature and humidity conditions. The method of vapor permeability resistance $R_п$ concerning an enclosing structure is proposed based on the distribution of sorption moisture along its cross-section.

Keywords: Vapor permeability, moistening condensation, temperature, fencing structures.

In the 90s there was a shift in the construction industry to an increased level of building thermal protection, which resulted in the use of multi-layer fencing structures with the use of an effective insulation layer. The processes of vapor transfer occurring in these structures are still poorly studied because of the lack of an accumulated testing base on vapor permeability under real operating conditions of a fence and a wide variety of modern insulating materials, and the combinations thereof with structural and facing layers of a fence.

Heat engineering specifications of fencing structures and their longevity depends on their moisture conditions in many respects. Nowadays an optimal humidity operation mode is governed by vapor permeability characteristics of the structure material layers. The vapor permeability of materials depends on a number of parameters for various reasons, including their specific sorption humidity and temperature. In the international standard ISO 10456:2007 two values of vapor permeability coefficient μ (mu) are specified for both dry and wet material. Some of the values are specified in Table 1, where they may be compared with native values.

Table-1: Vapor permeability of building materials on various reference data.

Building materials	density ρ kg/m^3	ISO 10456:2007		SNiP 23.02.2003
		μ mg/m·h·Pa (DRY MODE $φ_{cp}$<70%)	μ mg/m·h·Pa (WET MODE $φ_{cp}$>70%)	μ mg/m·h·Pa

Concrete with gravel or crushed stone	2400	0,0054	0,0088	0,03
Polyestyrene foam	10-15	0,012	0,012	0,02-0,05
Extruded polystyrene foam	20-65	0,0047	0,0047	0,005-0,013
Mineral wool	10-200	0,7	0,7	0,3-0,6
Cement-sand plaster	1800	0,07	0,117	0,09
Lime-sandmortar	1600	0,035	0,07	0,12

As this table shows the values of vapor permeability coefficient at an increased air humidity in the material are more than at the low one and this difference makes up to 200%. The paragraph 8.3 of the same standart specifies that during the design phase the vapor permeability values μ are selected on the basis of moisture mode in the material layer of a structure. If an average relative humidity in the material layer is below 70%, then it is a dry mode, if it is more than 70% then it is a wet mode. The SNIP 23-02-2003* specified only one value of the material vapor permeability coefficient μ (mu), that is, during the protection stage of a structure from overwetting the distinction between "dry" material layers and "wet" ones is not performed. So, according to this procedure, humid operation mode is one for all the material layers of the structure. This approach may lead to distortions at the determination of a condensation zone and the prediction of condensed moisture volume in an enclosure. Therefore, there is some uncertainty about the humid operation conditions concerning the structure material layers, and as a consequence the uncertainty of vapor permeability real values used in engineering calculations. V.M. Ilyinsky in his work [1] referring to the accumulated results of foreign researcher experiments (Johanson and Edenholm) indicated that the values of vapor permeability at different humidity of hydrophilic material may vary up to 3 times (Fig. 1). Perehozhentsev A.G., Gagarin V.G., Kozlov V.V., Kiselev I.Y. studies divide the transfer of moisture in material into various mechanisms, namely: the diffusion of vapor moisture, the transfer of film moisture and volumetric water. Based on these studies it can be stated that at the initial stage of the material hydration with vaporized moisture a movable film moisture is formed, which upon further material wetting (for example, at the moisture content of 0.9% for red brick [2]) it will clog the pores and prevent its diffusion of vaporous moisture. Thus, the vapor permeability coefficient with the material moisture increase will be decreased and the process of moisture transfer will occur mainly due to the movement of film moisture.

This relationship is illustrated in Perehozhentsev A.G. works [2] Figure 2. The emerged apparent contradiction between experimental dependences of vapor permeability (Figure 1) and calculated ones (Figure 2) lies in the method of material testing for vapor permeability.

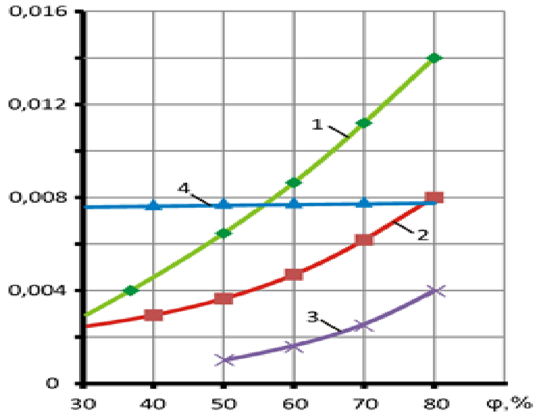

Figure 1 - The change of vapor permeability coefficient for building materials according to their moisture content (based on Johanson's and Edenholm's experimental data): 1 - lime mortar; 2 - cement mortar; 3 - dense concrete; 4 - mineral wool (wool).

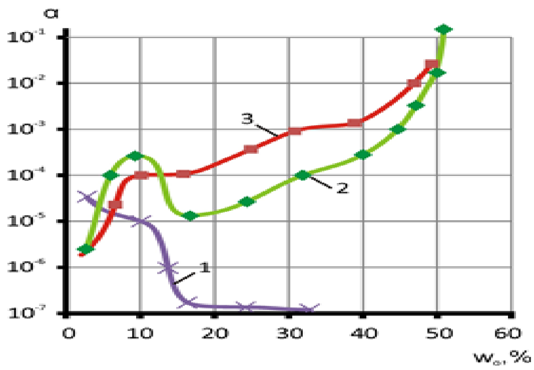

Figure 2 - The dependence of diffusion coefficients at T = 293 to vapor (1), film (2) and volumetric (3) moisture on the volumetric moisture content of keramzite concrete (1350 kg / m^3).

The analysis of standard methods for the determination of material vapor permeability (GOST 25898-83, GOST R EN 12086, GOST 12852.5-77, ASTM E96-80, et al.) allowed to reveal that the material samples are tested in a very limited range of conditions. Test conditions may be divided into "dry" and "wet" ones. "Dry" condition allows to form the decreased values of material moisture. On the one side of a sample 0% of air relative humidity is set (due tp water absorber), on the other side at least 50% of air relative humidity is set. When "wet" conditions are used an increased humidity is developed in the material, the relative humidity above and under the sample are equal to 100%/50% respectively. The schemes are displayed on Fig. 3.

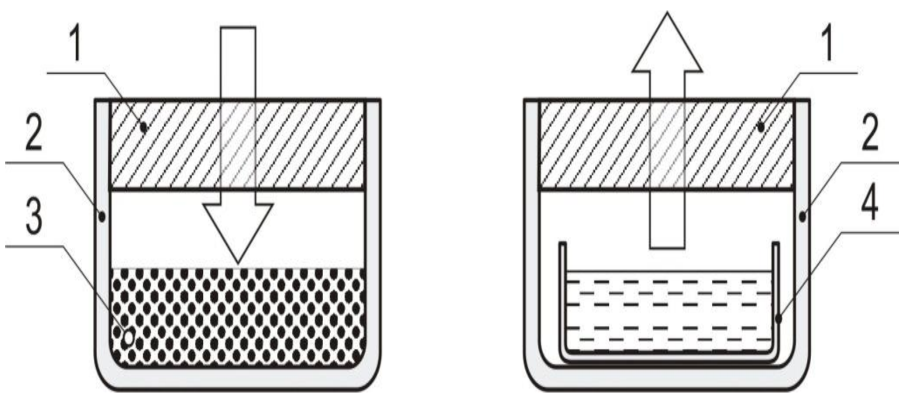

Figure 3 - The standard schemes of material water vapor permeability determination. 1 - material sample, 2 - cup 3 - desiccant, 4 - cell with water. The arrow shows the direction of water vapor movement. A dry method is on the left, a wet method is on the right.

The temperature is the same for all tests and is set in the various standards of the construction industry within the range of 20 ÷ 23 C. That is, when materials are tested to determine the vapor permeability a real temperature range in a fence is not standardized. Based on the above stated things, it can be assumed that a sample develops a movable film moisture in a wet test method at high air humidity (~ 75%) due to adsorption. Consequently, this test result will be not vapor permeability coefficient value, but the sum of mechanisms for film and vapor moisture transportation. In dry method the contribution of film moisture transportation is significantly lower than diffusions. Thus, a significant increase of vapor permeability coefficient observed in the experiments (Figure 1), and in the international standard ISO 10456:2007 should be interpreted as the sum of these mechanisms, and vapor permeability as the dependence of vapor moisture diffusion on the specific sorption wetness of the material. In order to recalculate the vapor permeability coefficient according to specific sorption material wetness V.M. Ilyinsky offered a simple formula [1]:

$$\mu_x=\mu_{80}\frac{w_x}{w_{80}} \quad \text{--- (1)}$$

where $\mu_{80}$is vapor permeability coefficient obtained experimentally at an average relative humidity of air in the material equal to 80%, w_{80}- an equilibrium moisture content of a sample at a relative humidity ofa80%, $w_x$and μ_x– desired equilibrium moisture content and vapor permeability coefficient, respectively, at relative air humidityx%. However, according to this formula, there is no separation of moisture transfer into different mechanisms described above. So at zero moisture sorption$w_x$according to formula (1) a porous material will be vapor impermeable. A good agreement of V. M. Ilyinsky formula with experimental data allows to use it for a rough estimate of the material permeability by film moisture and vaporous moisture excluding the permeability coefficient. Then the formula for the calculation of permeability coefficient by film moisture $\mu_{пл}$будетwill be as follows:

$$\mu_{пл}=(\mu_{80}-\mu_w)\frac{w_x}{w_{80}} \quad \text{---(2)}$$

where μ_w – permeability coefficient by vaporous moisture with the material moisture contentw_x.

It is worth noting here that $\mu_{пл}$in this case will be the numerical equivalent of vaporous moisture transfer.

Perehozhentsev A.G. gives the formula (3) in order to calculate the vapor permeability of the material by a vaporous moisture according to its particular sorption wetness:

$$\mu_w = \mu_0 (1 - \frac{w_x}{w_H}) \text{ ---(3)}$$

where μ_w – vapor permeability coefficient of a porous material with a volumetric moisture content ofw_x; μ_0 – vapor permeability coefficient of absolutely dry material; w_H – the value of material volumetric moisture content at full water saturation. Therefore, combining the formulas 2 and 3, we obtain the dependence of material vapor permeability on the moisture sorption taking into account both mechanisms:

$$\mu_x = (\mu_{80} - \mu_w)\frac{w_x}{w_{80}} + \mu_w \text{ ---(4)}$$

Therefore, if you know the real sorption moisture along the fencing structure sectionw_x, you adjust significantly the value of its vapor permeability. It should be noted that the applicability of the formula 4 is only possible when the transfer direction of the film and diffuse moisture is the same. According to Deryagin B.V. [3] the transfer of film moisture will occur due to emerging wedging pressure P(h) in a film along the thickness gradient of the adsorbed film moisture, i.e. in the direction of its smaller thickness. Basing on this fact one may assume that the movement direction of the film moisture will coincide with the gradient of sorptivemoisture in the material, that is from more moisturized to less moisturized areas. According to numerous studies performed by K.F. Fokin [4], A.U. Franchuk [5] V.G. Gagrin [6] the sorption moisture of the material depends on the temperature. So the material sorption humidity increases at temperature decrease. A variety of methods for the recalculation of humidity characteristics is developed at different temperatures and relative humidity. In particular, there are A.E. Pass, M. Polanyi, M.M. Dubnin, A.E. Alumyae, V.G. Gagarin methods in order to recalculate the material sorption wetness for different temperatures. So according to A.E. Pass method [7] thevalues of material sorption humidity was calculated in A.U. Franchuk reference book. The actual operating conditions of an enclosing structure outer layer are such that a significant temperature drop in its cross-section may appear during a cold season. Consequently, moisture sorption along the cross section of an outer layer will also be different and may increase to an outer surface. Under these conditions, the movement of a film moisture may be directed against the movement of vaporous moisture. Thentheformula 4 becomesasfollows:

$$\mu_x = \mu_w - (\mu_{80} - \mu_w)\frac{w_x}{w_{80}} \text{ ---(6)}$$

In order to use the formulas (3-5) the information about the distribution of sorptive moisture in the insulating materials of outer walls and its change throughout a year. We calculated the values of vapor permeability and vapor resistance$R_п$of an enclosing structure heat insulating layers taking into account their changing sorption humidity throughout a year. Formula 4 and 5 were chosen as the basis at the calculation of the specific of vapor permeability μ specific values according to the value of moisture sorption. A real fencing structure was taken as initial data performed like wet facade type with a thin plaster layer along a thermal insulation layer.Two structure data are brought as an example differing only by heat insulating material. The first structure is with the use of cellular concrete (its density makes 400 kg/m3), the second structure is with the use of mineral wool (its density makes 90 kg/m3). The structural layer is made of silicate bricks. The thickness of the insulation material in both cases is equal to 15 cm., and the construction material thickness makes 64 cm. The temperature and air relative humidity was measured in various sections of this structure between November and August in the pores of the material using the DTG-2.0 sensors, the data of an average relative humidity along the section of the insulating material for each month are shown on Fig. 4.

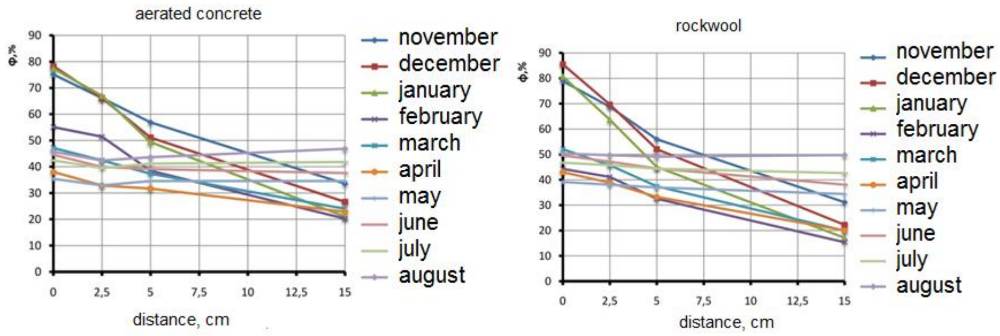

Figure-4: An average relative humidity distribution along the cross section for each month.

Fig. 4 shows that the relative humidity of the air along the cross section of a heat-insulating material changes significantly. In winter time, a relative humidity gradient of air appears along the material section and increases toward an outer surface. According to the average month indices of temperature and a relative humidity using the reference data from A.U. Franchuk the sorption humidity change schedules were developed for each section, Fig. 5.

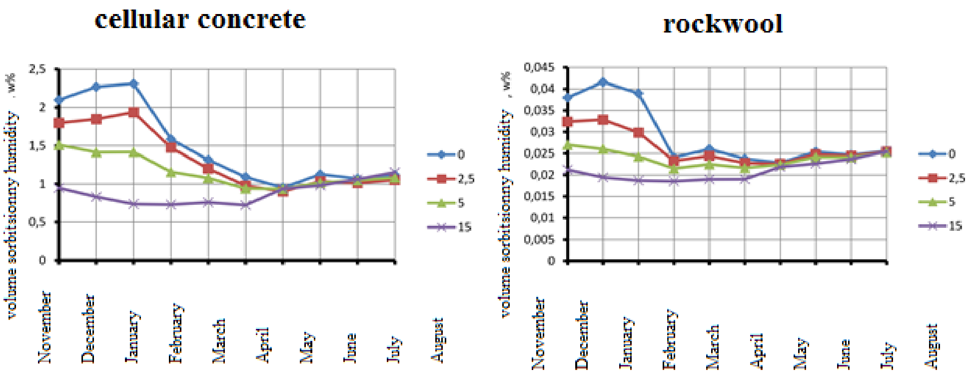

Figure-5: The distribution of volumetric sorption humidity for each section.

From Figure 5 it can be seen that the sorption moisture in thermal insulation materials varies throughout the year. The highest gradient of moisture sorption occurs in January and December and increases along the cross section to an outer surface. Since May, one may observe the alignment of sorption moisture along the section of a heat-insulating material.

During the construction of schedules for cellular concrete it was considered that the sorption humidity depends on the relative humidity and the temperature in a particular section. Unfortunately, there is no reference literature concerning sorption moisture data of mineral-cotton insulations at different temperatures, so it is assumed that the sorption humidity of mineral wool depends only on the relative humidity of air. According to the obtained values of sorption moisture the values of μ coefficients and vapor permeability resistance$R_п$of thermal insulation layers for each month were calculated for each month, Figure 6.

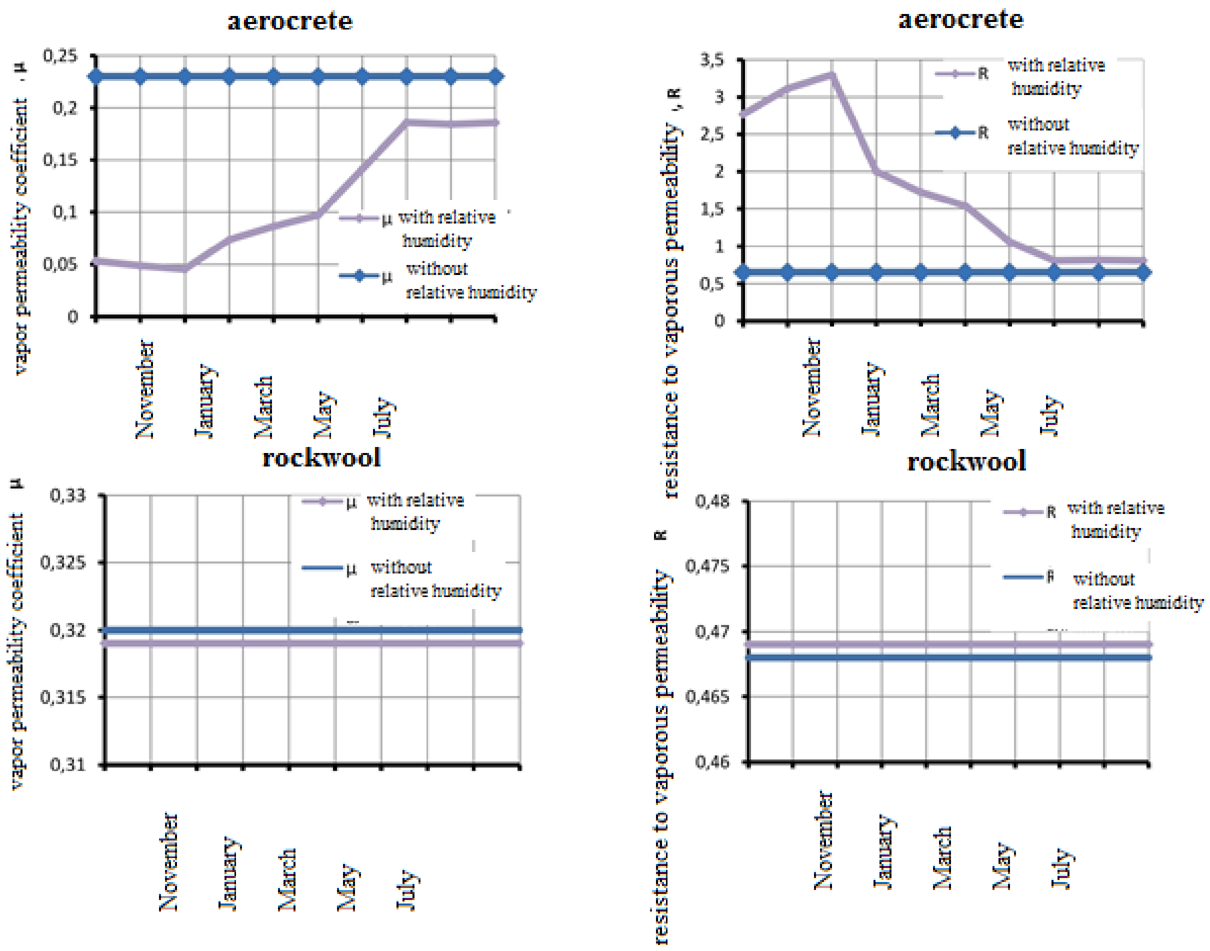

Figure-6: The nature of vapor permeability μ value change and the resistance to vaporous permeability $R_п$ of thermal insulation materials from November to August.

Then the method for the resistance value calculation $R_п$using the example of the layer made of cell concrete for January:

1. According to the graphs of an average relative humidity and temperature distribution in a heater section, which are obtained in natural experiment, the schedule of moisture sorption distribution is developed.

2. According to the schedule of sorption moisture distribution using the formula (5) the values of vapor permeability μi are determined for the selected section points, and the dependence schedule for reciprocal value of vapor permeability 1/μi is created along the thickness of insulation (Fig. 7). The calculation of one value 1/μ0 in the point "0" is demonstrated as an example, which corresponds to an outer surface of the wall section.

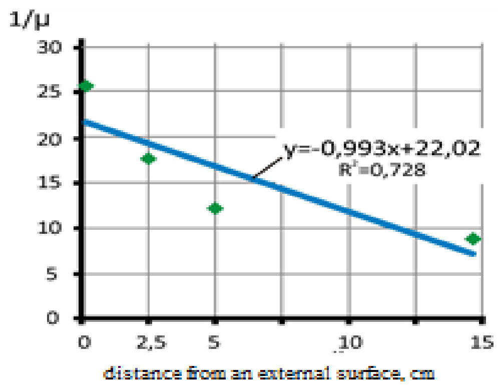

Figure-7: Linear dependence 1/μ creation according to obtained points.

$\mu_x=\mu_w-(\mu_{80}-\mu_w)\frac{w_x}{w_{80}}$;

$\mu_w=\mu_0(1-\frac{w_x}{w_H})$;

$\mu_w=0{,}144(1-\frac{2{,}31}{49{,}8})=0{,}137$ mg/m·h·Pa

$\mu_x=0{,}137-(0{,}23-0{,}137)\frac{2{,}31}{2{,}15}=0{,}038$ mg/m·h·Pa

$1/\mu_0=26{,}49$ mg/m·h·Pa

3. According to schedule design points (Figure 7) the mathematical function 1/μ (y) from the distance of an outer insulation surface (x).

y = -0,993x + 22,02(6)

4. Having integrated this function along the insulation thickness the vapor permeability resistance value $R_п$is determined for this layer

$$R_n=\int_0^{0,15}(-0{,}993x+22{,}02)dx=3{,}29\ \text{m}^2\cdot\text{h}\cdot\text{Pa/mg}(7)$$

Figure 6 demonstrates the schedules of vapor permeability coefficient μ and the resistance values to vapor permeability$R_п$obtained taking into account the changes of sorption moisture in the material and without taking it

Conclusion

1. The value of vapor permeability μ of heat insulation layers for an enclosing structure is not a constant value.
2. During the study of an outer wall structure according to "wet" facade type in the climatic conditions of the city of Kazan it was found that the resistance value to vapor permeability of aerated concrete varies during the year by more than 3 times, while$R_п$of mineral wool is hardly subject to change.
3. Experimental data allowed us to estimate the range of resistance variation to vapor permeability and to establish that for the structure with the use of a thermal insulation layer from cellular concrete with the density of 400 kg/m3, this range makes 0,8-3,29 m2•h•Pa/mg. The calculation of aerated concrete according to reference values μ = 0,23mg/(m·h·Pa) provides the value $R_п$= 0,65 (m^2·h·Pa/mg).
4. The method for the calculation of resistance to vapor permeability$R_п$is proposed for a fencing structure taking into account the distribution of sorption humidity along its cross section.

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