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Thermal technical properties of insulation materials made from easy renewable row sources

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Summary

The paper presents the results of research focused on heat technical properties of insulating materials from easily renewable organic raw materials, especially from insulations based on technical hemp and other possible raw material sources from agriculture (flax, jute) which can be potentially used for the production of heat insulation. Within the scope of research a study was elaborated with the aim to verify, whether the heat technical properties of above mentioned materials are comparable with the properties of classical heat insulating materials such as polystyrene foam or mineral wool. It can be even assumed that from the standpoint of some specific properties the newly developed materials will dispose with better properties. Within the scope of research first of all the effect of moisture was followed up on the heat technical properties of these materials.

KEYWORDS: insulation materials, thermal conductivity, organics materials, technical hemp.

1. INTRODUCTION

At present we are continually fighting with problems concerning the quantity of crude oil resources which are the mostly used raw material in the production of cellular plastics insulations.

The basic advantage of organic raw materials is in comparison with other raw materials their theoretically inexhaustible production. This fact has advantages, such as the low production costs of raw materials processing with subsequent manufacture of products, further the generally low ecological burden and the easy recycling of materials after exhaustion of their service life. Another serious reason of the fact that the heat insulations based on organic fibers gain still larger popularity in recent years, are the positive properties of these materials in the field of natural moisture accumulation, high diffuse openness.

2. MOISTURE INFLUENCE

The moisture has markedly effects at the heat technical properties of building materials. The most cellular building materials contain under normal conditions a certain percentage of moisture even in the dry state. The quantity of this moisture depends on the porous system of the material, on the relative humidity of the surrounding and on the temperature. The most important material properties influencing the moisture are the properties of the porous system (form, size, openness and distribution of pores). The moisture propagation in the construction takes place chiefly by the diffusion of water vapour and by capillary conduction. The moisture transfer takes place from the place with higher moisture in the place with lower moisture (in the direction of moisture drop or of the water vapour partial pressure drop).

The equivalent value of the heat conduction coefficient of the building material depends on its moisture therefore it is necessary in the course of real calculations to consider the immediate moisture of the building material in the construction and its steady moisture during the use of the construction. The part of the standard heat technical calculation of building structures is their evaluation in the light of water vapour diffusion and condensation, with respect to the change of the building material heat technical properties.

The elevated moisture of the material in the structure can come from different sources. The moisture of the building material can be differentiated according to its origin as: the moisture formed during the manufacture, the technological moisture, the rainfall moisture, the soil moisture and the process moisture.

3. BEHAVIORS OF BUILDING MATERIALS AFTER BUILD IN TO THE CONSTRUCTION

Owing to the moisture electric field is generated in building materials. It is caused by the different mobility of the solved salts and by the different pH values. The electric field is a strong degrading factor in particular of metallic components built in the building structures.

The water or the moisture has a very high degrading effect both at he building material and at the building structure as a whole. The effect of water causes the corrosion of the frame structure and changes of some important building material properties.

The degrading changes caused by water effect can be *reversible* i.e. after the decrease of moisture the original properties of the material (construction) are recovered, and *irreversible,* when permanent damage of the building structure is caused by the effect of water and moisture even after the subsequent decrease of moisture.

3.1 Dependence thermal conductivity on moisture content

The equivalent value of the thermal conductivity of building materials is very close connected with the moisture content. The thermal conductivity λ $[W.m^{-1}K^{-1}]$ of the wet material is determined by the thermal conductivity of the solid matrix, of fluid phases, of gaseous phases and their quantity, by phase changes and by the spatial distribution of phases. Thermal conductivity value increases in general with the rising moisture content of material.

Thermal conductivity of the totally dry, porous material can be simply expressed by the following equation:

$$\lambda_{dry} = \lambda_{mat} \cdot (1 - P) + \lambda_{vzd} \cdot P \tag{1}$$

λ_{dry} thermal conductivity of dry material $[W \cdot m^{-1} \cdot K^{-1}]$,

λ_{mat} thermal conductivity of the solid material (matrix) without pores $[W \cdot m^{-1} \cdot K^{-1}]$,

λ_{vzd} thermal conductivity of air $[W \cdot m^{-1} \cdot K^{-1}]$,

P porosity [-].

In the case of material with moisture content, the air pores are gradually filled by water. The increase of thermal conductivity is in the area of low (hygroscopic) humidity sharper. In the area of higher humidity the intensity of the heat conduction coefficient grow, usually decreases in dependence on the increase of the moisture content.

Thermal conductivity of the wet material can be simply expressed in dependence on moisture content by relations bellow:

a) Area of low moisture content (hygroscopic moisture), $\lambda_{(w)}$*:*

If we consider the heat bridges, which exist in the air-dry material under normal conditions by the effect of continual smallest pores filling still by moisture w_{min} (see above) and the boundary hydroscopic moisture of the material $w_{h,max}$, we obtain for the thermal conductivity of the material $\lambda_{(w)}$ [W.m^{-1}.K^{-1}] the following relation:

$$\lambda_{(w)} = \lambda_{mat\,(u,\varepsilon)} \cdot (1-P) + \lambda_{vody} \cdot (w - w_{\min}) + \lambda_{vzd} \cdot (P - w) \tag{2}$$

$$\lambda_{mat(w,\varepsilon)} = \frac{1}{\dfrac{1}{\lambda_{mat(w)}} + \dfrac{3\,\varepsilon \left(1 - \dfrac{w}{w_{\min}}\right)}{\lambda_{vzd}\,(1-P)}} \tag{3}$$

$$\lambda_{mat(w)} = \frac{1}{\dfrac{1}{\lambda_{mat}} + \dfrac{w - w_{\min}}{\lambda_{vody}} + \dfrac{w_{h\max} - w}{\lambda_{vzd}}} \tag{4}$$

$$\varepsilon = \frac{1-2\upsilon}{E_m\,V_m} \int_{p_{c1}}^{0} \frac{w(p_c)}{w_{sat}} \tag{5}$$

υ	poisson constant [-],
E_m	modulus of elasticity [Pa],
p_c	capillary pressure [Pa],
V_m	matrix volume in the volume of material [-],
w	moisture of the material [-],
w_{sat}	moisture of the material after saturation by moisture (in saturated state) [-],
$\lambda_{mat\,(w,\varepsilon)}$	thermal conductivity of the material matrix, respecting material volume changes by the effect of its moisture content [W.m^{-1}.K^{-1}].

b) Area of high moisture content (outside of hygroscopic moisture area), $\lambda_{(w)}$

After reaching the maximum of hygroscopic moisture $w_{h\,max}$ the capillary system is filled by moisture and the parallel system expressing thermal conductivity is modified by the zigzag effect of the with moisture unevenly filled capillary system. This effect can be quantified by the introduction of the uniformity factor R. This factor can be determined on the basis of the porous system structural parameters. The following relation is valid in general (Meng 1994):

$$R = P_{rel}^{FD} \tag{6}$$

P_{rel} relative porosity [-]

FD factor of the porous system dimensions[-]

The factor of the porous system dimensions is defined (Meng 1994):

$$FD = \frac{\Delta \log P}{\Delta \log r} \tag{7}$$

In the area of similarity f, we can use for the calculation the relation:

$$R_f = w_f^{FD} \tag{8}$$

The final value of the humid material heat conduction coefficient $\lambda_{(w)}$ [W.m^{-1}.K^{-1}] , behind the area of hygroscopic moisture can be expressed:

$$\lambda_{(w)} = \lambda_{mat\,(u)} \cdot (1-P) + \lambda_{vody} \cdot \sum_f w_f \; R_f + \lambda_{vzd} \cdot (P-w) \tag{9}$$

f number of considered porous fractions, w_f . R_f is the autocorrelation function expressing the deviation of real pores from the parallel capillaries arrangement in the ideal model.

3.2 Dependence thermal conductivity on density

The heat conduction coefficient of the insulating material depends on the volume weight. In the case of materials with very low volume weight $\rho_v \leq 100$ kg.m^{-3} the situation is somewhat complicated. The heat conduction coefficient decreases with the increasing volume weight in the area with low volume weight, because the heat transfer by convection and radiation is limited in the porous structure of the material. After reaching the optimal volume weight, when the heat conduction reaches its minimum, the heat conduction begins gradually to increase with the volume weight increasing. This effect is caused by the increase of heat transfer by conduction through the material structure of the insulating material.

4. REVIEW OF RESULTS

Samples of heat insulating materials obtained directly from organic raw materials in agricultural production were used for laboratory measurements. In the concrete it concerned samples of technical hemp, flax and jute.

In the scope of research 8 samples were tested, they are presented in table 1.

Table 1. Review of basic properties of testing samples (dry stage)

Sample	Material source	a [m]	b [m]	h [m]	ρ_v [kg.m^{-3}]
1.1	juta	0,3	0,3	0,076192	24,4
2.1	len	0,3	0,3	0,076271	29,6
3.1	konopí	0,3	0,3	0,076875	29,0
4.1	konopí	0,3	0,3	0,069171	30,4
5.1	konopí	0,3	0,3	0,065265	53,0
6.1	konopí	0,3	0,3	0,02936	33,5
7.1	konopí	0,3	0,3	0,009552	102,5
8.1	konopí	0,3	0,3	0,038395	80,9

Comment: a, b, h – size of sample, ρ_v - density

The test samples were conditioned at the temperature +23°C in media with different relative humidity in order to determine their sorption characteristics. The quantity of moisture which was accepted by given materials into their structure depends on the relative air moisture, on the temperature and on structure of these materials.

The test samples were stored in below mentioned media, with the following parameters:

- *dry environment* – relative humidity 0 % a temperature +23°C (samples was dry to constant weight),
- *normal environment* – relative humidity 50 % a temperature +23°C,
- *wet environment* – relative humidity 80 % a temperature +23°C.

The quantity of moisture accepted by the test samples into their structure you will find in table 2. The measured values are presented in the form of the sorption isothermal line. The determination of the sorption isothermal line was realized at

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the temperature + 23°C. The humidity by weight of test samples was measured at the relative humidity 50 % and 80 %. The results of measurements are presented in the following table 2 and figure 1.

Table 2. Review of dependence of moisture content on relative humidity (environment temperature +23°C)

φ [%]	**Sample 1** **w_m [%]**	**Sample 2** **w_m [%]**	**Sample 3** **w_m [%]**	**Sample 4** **w_m [%]**	**Sample 5** **w_m [%]**	**Sample 6** **w_m [%]**	**Sample 7** **w_m [%]**	**Sample 8** **w_m [%]**
0	0	0	0	0	0	0	0	0
50	6,52	6,73	6,08	5,18	5,23	5,20	4,83	5,30
80	12,57	12,90	11,62	11,32	9,86	9,93	10,07	10,44

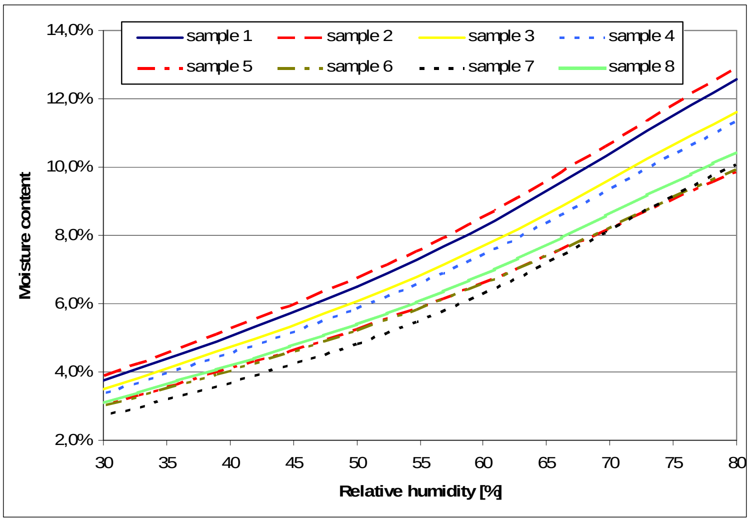

Figure 1. Samples moisture course in dependence on humidity (environment temperature +23°C)

On the base of presented results we can generally state that the moisture of the test samples increases with the increase of the air relative humidity. The highest content of moisture by weight showed the flax sample 2, and on the contrary the smallest content of moisture by weight had the sample 5.

Further the heat conduction coefficient was determined in dependence on the humidity of the surrounding in which the test samples were stored. The determination of the heat conduction was measured by the stationary desk method at the temperature +10°C and at the temperature drop 10°C.

Table 3. Review of measured values of thermal conductivity and moisture content in dependence on relative humidity (environment temperature +23°C)

Vzorek	**φ [%]**	**0**	**50**	**80**
1	**w_m [%]**	0	6,52	12,57
	λ [$W.K^{-1}.m^{-1}$]	0,0469	0,0482	0,0538
2	**w_m [%]**	0	6,73	12,90
	λ [$W.K^{-1}.m^{-1}$]	0,0431	0,0442	0,0537
3	**w_m [%]**	0	6,08	11,62
	λ [$W.K^{-1}.m^{-1}$]	0,0485	0,0500	0,0584
4	**w_m [%]**	0	5,184	11,32
	λ [$W.K^{-1}.m^{-1}$]	0,0474	0,0488	0,0582
5	**w_m [%]**	0	5,23	9,86
	λ [$W.K^{-1}.m^{-1}$]	0,0407	0,0419	0,0502
6	**w_m [%]**	0	5,20	9,93
	λ [$W.K^{-1}.m^{-1}$]	0,0429	0,0441	0,0477
7	**w_m [%]**	0	4,83	10,07
	λ [$W.K^{-1}.m^{-1}$]	0,0467	0,0482	0,0508
8	**w_m [%]**	0	5,30	10,44
	λ [$W.K^{-1}.m^{-1}$]	0,0395	0,0405	0,0452

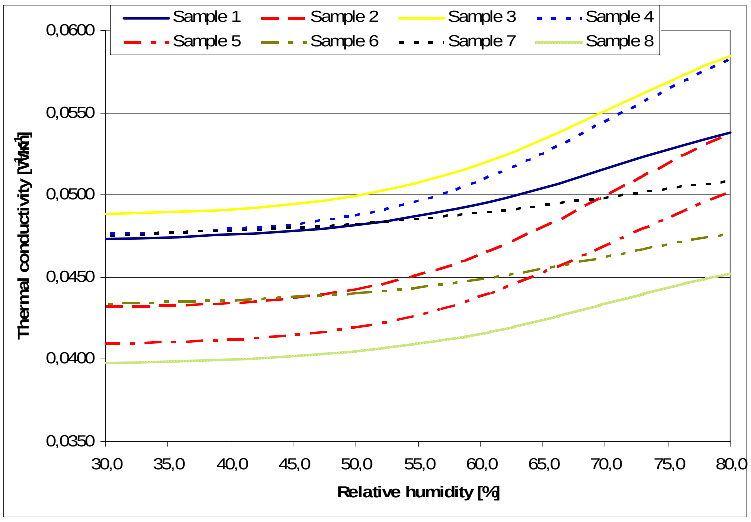

Figure 2. Dependence of thermal conductivity on relative humidity (environment temperature +23°C)

The presented dependences show that the greatest moisture sensitivity had the samples no.2, 4 and 5.

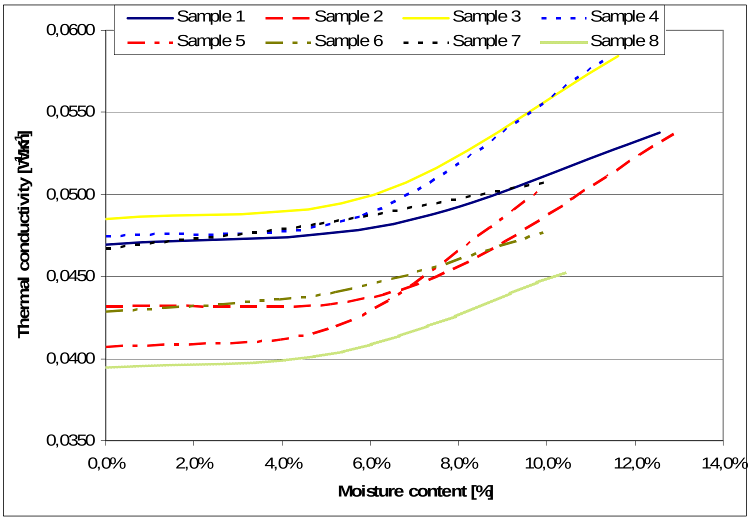

Figure 3. Dependence thermal conductivity on moisture content (environment temperature +23°C)

5. CONCLUSION

According to the above mentioned dependences we can state, that the tested organic materials are sensible to the humidity of the medium in which they are situated and in which they are built in. However when these materials are not in direct contact with liquid water and are not exposed to surroundings with the partial water pressure higher than 1500 Pa (23°C, 50% RH), they show no significant deterioration of heat insulating properties.

For prediction of behavior of thermal insulating materials is very important to know dependence on the thermal conductivity on ambient humidity. This property can be one from most important properties from point of view of selection of optimal material for special realization of building construction.

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