IOP Conf. Series: Materials Science and Engineering **660** (2019) 012072 doi:10.1088/1757-899X/660/1/012072

Effect of modified liquid glass on absorption humidity and thermal conductivity of flax fiber slabs

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Abstract. Thermal insulation materials based on vegetable fibers are considered. The results of studies on the microstructure of flax fiber noils using a light microscope and flax fibers using electron microscopy are presented. The complex of studies on the selection of the composition of thermal insulation slabs from flax fibers and flax noils has been conducted to determine the process of absorption of humidity from the air. The humidity absorption of insulants based on flax fibers and flax noils has been determined at a relative humidity of 40–97% using sodium liquid glass and modified liquid glass, as well as «Akotherm flaks» slabs. The thermal insulation slabs water vapor absorption kinetics has also been investigated, taking into account the time parameter. The effect of absorption humidity on the thermal conductivity of the studied materials has been examined; for this purpose, the coefficients of thermal conductivity of materials with the maximum humidity content of insulators were determined. The results of the tests indicate the highest efficiency of thermal insulation slabs made of flax fiber tow compared with insulation materials based on flax fibers and «Akotherm flaks» slabs.

1. Introduction

The development of ecological “green” building in recent years has significantly changed the perception of many developers. Now they often impose requirements on the environmental safety of facilities along with traditional quality indicators for buildings being erected. It should be noted that the construction industry, both in Belarus and in other countries, is not always ready to meet the environmental requirements of customers. First of all, this problem is associated with the limited availability and release of environmentally friendly building materials. The greatest problems of the manufacturing sector are connected with the production of thermal insulation materials since traditional insulants (foam polystyrene and slag wool) do not meet the requirements for ecology. One of the best solutions to the current situation is to use plant materials of natural or agricultural origin in combination with environmentally friendly binders for the production of thermal insulation materials. Several researchers note that an increase in the use of plant waste will not only provide construction with additional raw materials and expand the range of local building materials, but also contribute to the conservation and rational use of natural resources [1–3].

In many countries, technologies for utilization of crop waste for wall and thermal insulation materials are being implemented, which indicates considerable interest and the need for further development of this construction industry segment.

The manufacture of thermal insulation slabs made from wood fibers is one of the most developed productions of insulation materials. Among the wood fiber insulation materials on the market, mainly products of foreign companies dominate - STEICO (Germany - Poland), GUTEX (Germany) and Skano Group (Estonia) [4]. Recently, manufacturers from Russia have intensively mastered the production technology of such materials. The following technical indicators characterize insulators: density 150–250 kg/m^3, thermal conductivity 0.06 W/(m·K), flexural strength 0.5–1.2 MPa [5].

The use of oil palm bark fibers in the form of aggregate for insulating slabs is also known [6]. The binder is sodium liquid glass. The insulant has a density of 200 kg/m^3 and provides a thermal conductivity of 0.052 W/(m·K), a flexural strength of 0.75 MPa and compressive strength at the 10 % deformation of 0.21 MPa.

It is also suggested to use the technical hemp shives to obtain thermal insulating slabs [7]. Hydraulic lime is insulation binder. At a density of 312–337 kg/m^3, the compressive strength of the material reaches 0.179–0.222 MPa, and the coefficient of thermal conductivity is 0.101–0.087 W/(m·K). The material can be used in low-rise construction.

Studies of dry molding thermal insulating materials in the Kostroma State Technological University, consisting of flax shive particles with the addition of up to 8% resin and 1% paraffin, have been carried out [8]. In the process of research, it was determined that at a density of 40 kg/m^3 the insulation has a thermal conductivity of 0.101 W/(m·K). Slabs of similar composition are made in Thailand, the United Kingdom, and Canada.

Ecological slabs "Thermo-Hanf" from hemp fibers are produced in Germany. Thermal insulation material consists of hemp fibers by 83–87% and polyester by 10–12% [9, 10]. As fire-retarding material, soda is added in an amount of 3–5% of the total mass. Thermo-Hanf insulation is used for warming roofs, walls, floors, inter-floor and attic floors. The insulation thermal conductivity is 0.038–0.04 W/(m·K) at a density of 35–40 kg/m^3. Due to the low density, the insulating material is not rigid, which somewhat limits the area of application, and the high price prevents the popularization of insulation.

An effective insulating material in the form of semi-rigid slabs based on waste cotton fibers and liquid sodium glass is an innovative invention of Turkmenistan and other countries of Central Asia [11]. The thermal conductivity of the insulation is 0.037–0.039 W/(m·K), at a density of 40–90 kg/m^3.

Thermal insulating slabs based on peat moss and liquid glass have also been developed. Their thermal conductivity coefficient is 0.034–0.04 W/(m·K), and the density equals to 155–170 kg/m^3. However, insulation slab based on moss has a drawback - significant shrinking deformation of the material during the drying process [12]. To eliminate this problem, it was suggested to introduce milled straw in the amount of 20–30% by weight of moss.

Flax fiber waste is of considerable interest in the production of thermal insulation materials in the Republic of Belarus. More than 20% of flax crops of the European continent are concentrated on the territory of Belarus. In 2017, the yield of flax fiber was 9.2 c/ha, the highest yield was observed in 2014 and amounted to 10.7 c/ha [13].

Harvesting and further processing of flax to produce fibers is a rather laborious process. When harvesting flax with combine harvesters mechanized spreading of straw on flax is produced. The separation of the fibrous part of the stem from wood is promoted by dew, rain, and heat, which destroy connective tissues. Next, flax raw material goes to flax factories for the primary processing of flax [14]. When processing flax straw, more than one-third of the total fiber goes to flutter waste. After the usual shaking out from the tow, part of the waste is used as oakum. Most of the waste is carefully treated on a special line of machines for the production of short fibers. These machines consist of a special dryer, shaker, and tow preparing machine. Here, flax waste is finally cleared of tow. To improve the quality of the fiber, clean, short, and long fiber after assessment and garters is transported to the warehouse for retrieval. Then the fiber passes the control sorting and is sent to flax industrial plants or factories [15]. As a result of flax dressing, from 45 to 55% of dressed flax, 40-50% of noils and about 5% of tow are obtained.

The well-known development of insulation based on flax fibers includes thermal insulation slabs «Ecoteplin» produced in Russia. The binder is starch. Borates are used as fire- and bio resistance agents [16, 17]. The slabs are used both in low-rise construction and for thermal and acoustic insulation of apartment buildings. The material «Ecoteplin» has antiseptic properties and is completely safe for human health. The density of thermal insulation slabs is from 32 to 34 kg/m^3, they ensure thermal conductivity of 0.037 W/(m·K), water absorption capacity by volume – 0.5 and water vapor permeability – 0.4 mg/(m·h·Pa). The insulation is a low combustible material. The widespread use of «Ecoteplin» is constrained by the high cost and limited use due to its low density. Also, the insulation material is highly water permeable and gets wet quickly, so the insulated walls should be additionally insulated with a special membrane.

The company JSC «Akotherm flaks» (Orekhovsk, Belarus) offers thermal insulation slabs containing 85% of flax fibers. Synthetic fibers are used as a binder (15%) [18]. The material is used in low-rise construction for thermal insulation of walls and floor slabs. At the density of 32 kg/m^3, thermal conductivity rate of «Akotherm flaks» is 0.038–0.04 W/(m·K), acoustic absorption coefficient – 0.84, vapor permeability – 0.4 mg/(m·h·Pa), and is classified as highly combustible materials. The high fire risk is the main disadvantage of the insulator. The material is characterized by low density, and that does not allow producing rigid compression-resistant insulating slabs, which is another factor limiting the application of «Akotherm flaks».

Currently, in the laboratories of the Department of Construction Industry in Polotsk State University, comprehensive studies on the development of flax noils thermal insulation materials are being carried out. As alternatives to flax noils thermal insulation slabs, samples with flax fiber filler and «Akotherm flaks» insulator are being studied. Using flax noils for making slabs solves the problem of recycling flax plant waste and expands the range of efficient thermal insulation materials produced from flax fibers.

2. Materials and Methods

Studies were performed on samples with fillers of flax noils or fibers produced on Postavy Flax Factory (Belarus).

Analysis of the microstructure of flax noils and flax fibers was carried using optical and electron microscopy performed on microscopes Altami MET 5C and JSM-5610 LV.

In the manufacture of thermal insulation slabs, sodium liquid glass produced on JSC Domanovsky Production and Trade Plant was used as a binder. This sodium liquid glass met the requirements of GOST (ГОСТ) 13078. The second part of the research was carried out on a modified liquid glass. In the form of an additive, hydrated lime grade II without additives produced by JSC Zabudova was used, as well as gypsum made at JSC Belgips and meeting the requirements of STB EN 459-1 and GOST (ГОСТ) 125-79.

Flax noils and flax fibers thermal insulation samples were prepared in the form of slabs with dimensions of 250×250×50 mm. When preparing the samples, a certain sequence of technological operations were observed. A pre-dosage of the components was made. To obtain a modified binding agent, lime was first added to the liquid glass and mixed to a smooth consistency, only after that gypsum was added. Sodium liquid glass or modified liquid glass with fibrous filler was mixed placed in the mold. The samples of thermal insulation materials were kept in the mold for 6 hours at a temperature of 20 ± 2 °C. The samples were then removed from the mold and dried for 4 hours in a drying chamber at a temperature of 45–55 ° C. The samples based on flax and polyester fibers mixture were cut from «Akotherm flaks» thermal insulation slabs. Each sample of thermal insulation materials was placed in an individual pressurized chamber with pre-poured water 40 mm below the slab installation level. The air temperature in the chamber corresponded to 20 ± 2 °C, and the relative air humidity was 97%. The slabs were kept in a chamber above water until the equilibrium humidity was reached, after that the slabs were removed and the thermal conductivity coefficient was determined. Thermal conductivity coefficient was determined according to STB (СТБ) 1618 and using a thermal conductivity meter ИТП-МГ4.

The absorption humidity of thermal insulation slabs from flax noils has been determined according to GOST (ГОСТ) 24816. Pre-dried to constant weight samples with a filler made of fibers or flaxes,

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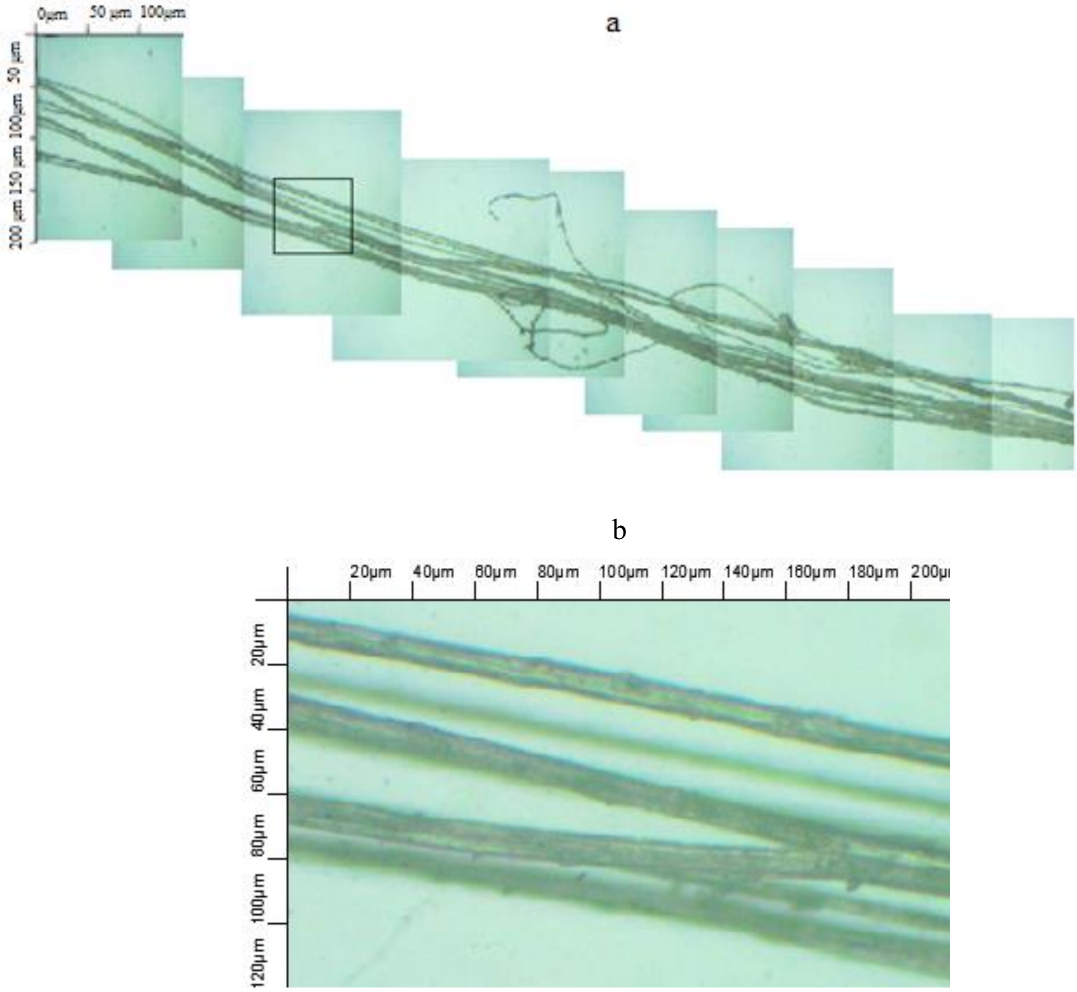
selected from thermal insulation materials, were placed in desiccators. The vapor-air environment in the desiccators was created artificially with the help of sulfuric acid chemical solution of different concentrations, providing a relative humidity of 40–97%. The humidity content of the samples was determined by weighing them after a fixed time before the start of the desorption process. The maximum humidity was taken as an indicator preceding the onset of desorption. When determining the absorption humidity of samples, the air temperature in the desiccators and the room corresponded to +20 ± 0.5°C.

3. Results and Discussion

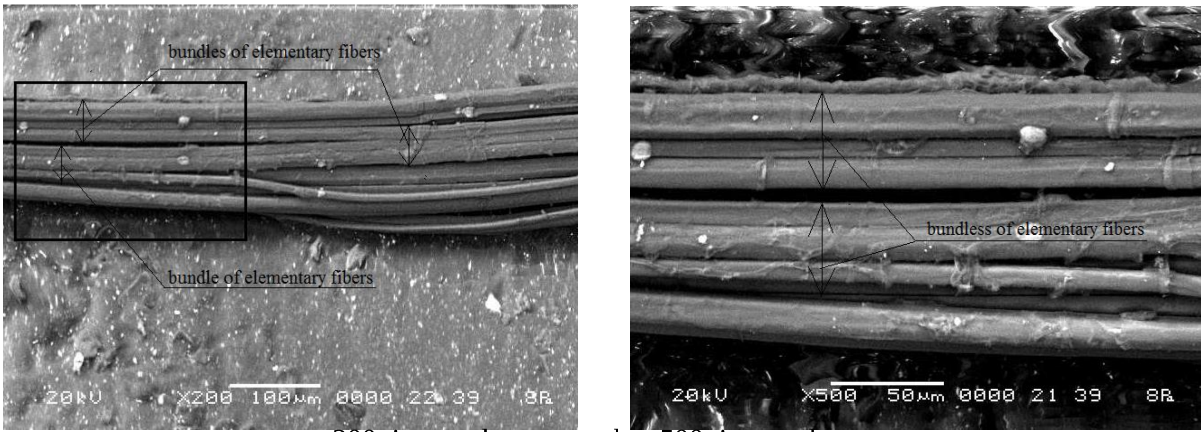
The image of a flax noil (Figure 1 a) was obtained with light microscopy combining the pictures of the consequently placed fragments of the analyzed sample. The fragment highlighted by the frame in figure 1 a is presented in the enlarged form in figure 1 b. Application of a scanning electron microscope allowed visually attesting that the flax fiber consists of bundles of elementary fibers (Figure 2 a). In the image of the fiber, the frame highlights the fragment that is enlarged in figure 2 b.



a – outer appearance of the noil, b – enlarged fragment.

Figure 1. Light microscopy of a flax noil.

a b



a – 200 times enlargement, b – 500 times enlargement

Figure 2. Electron microscopy of a flax fiber.

It was established that the flax webs are disheveled bundles of elementary fibers having randomly arranged contact connections among themselves. The length of the elementary fibers varies from 10 to 40 mm, with a diameter of 8–12 microns. Flax fiber is bundled with elemental fibers. The diameter of bundles is 50–70 microns, with a content of 10 to 20 elementary fibers in the structure. Obtained data are supported by Kil'chevskij A. V and Hotyleva L. [19].

Initially, to determine the quantitative composition of experimental samples of thermal insulation materials, the average density was varied at a constant flow rate of liquid glass – 10 kg. The quantitative composition and physic-mechanical characteristics of the obtained samples in dry condition are given in Table 1.

Table 1. Quantitative composition and physic-mechanical characteristics of materials.

No. of composition	Component consumption per 1 m^3, kg			Density, kg/m^3	Thermal conductivity, W/(m·K)	Compressive strength at 10% deformation, × 10^{-2} MPa
	flax fibers	flax noils	liquid glass			
1	45	-	10	55	0.047	0.2
2	60	-	10	70	0.042	0.3
3	75	-	10	85	0.043	0.36
4	90	-	10	100	0.045	0.42
5	-	45	10	55	0.04	0.13
6	-	60	10	70	0.035	0.21
7	-	75	10	85	0.036	0.25
8	-	90	10	100	0.038	0.3

Increasing the amount of aggregate to increase the insulation density to 70 kg/m^3 leads to a decrease in thermal conductivity, regardless of the fibers type (Table 1). A further increase in the density of the samples (compositions 3, 4, 7, and 8) causes an increase in the parameter under study. For example, at a density of 55 kg/m^3 for flax noils-based thermal insulation, thermal conductivity is equaled 0.04 W/(m·K). A decrease in thermal conductivity coefficient to 0.035 W/(m·K) occurs with a 1.3 times increase in density to 70 kg/m^3. With an increase in the average density up to 100 kg/m^3, an increase in thermal conductivity up to 0.038 W/(m·K) is noted. For flax fiber slabs, a similar relationship is established, since the minimum thermal conductivity coefficient value of 0.042 W/(m·K) corresponds to a density of 70 kg/m^3. A decrease in density to 55 kg/m^3 and an increase to

100 kg/m^3 leads to an increase in the thermal conductivity coefficient by 0.005 W/(m·K) and 0.003 W/(m·K), respectively.

Obtained results (Table 1) show that an increase in the average density of thermal insulation slabs at a constant binder consumption leads to an increase in compressive strength at 10% deformation. At a density of 55 kg/m^3 of flax noils materials, the compressive strength is $0.13 \cdot 10^{-2}$ MPa. An increase in the average density by 1.8 times leads to an increase in strength by 2.3 times to $0.3 \cdot 10^{-2}$ MPa. Insulation samples based on flax fibers with a maximum density of 100 kg/m^3 reach the strength of $0.42 \cdot 10^{-2}$ MPa. The decrease in the average density to 55 kg/m^3 causes a decrease in the compressive strength index at 10% deformation by 2.1 times. It should be noted that in the density range under study, the compressive strength of flax fiber-based thermal insulation materials is on average 45% higher than insulants from flax fiber noils.

Due to the low compressive strength of plant raw materials with fibrous structure, the data obtained when choosing the composition of samples of thermal insulation slabs were not taken into account. Thus, sample compositions with an average density of 70 kg/m^3 with the best thermal conductivity were used to study the absorption humidity of insulants. When the density of flax fiber-based insulation is 70 kg/m^3, the coefficient of thermal conductivity is 0.042 W/(m·K). When replacing flax fibers with noils, there is a decrease in thermal conductivity by 20% to a value equal to 0.035W/(m·K). Also, «Akotherm flaks» slabs samples with a thermal conductivity of 0.04 W/(m·K) and a density of 34 kg/m^3 were used in the studies. The applied technology of forming and structuring insulation does not allow producing material of higher density.

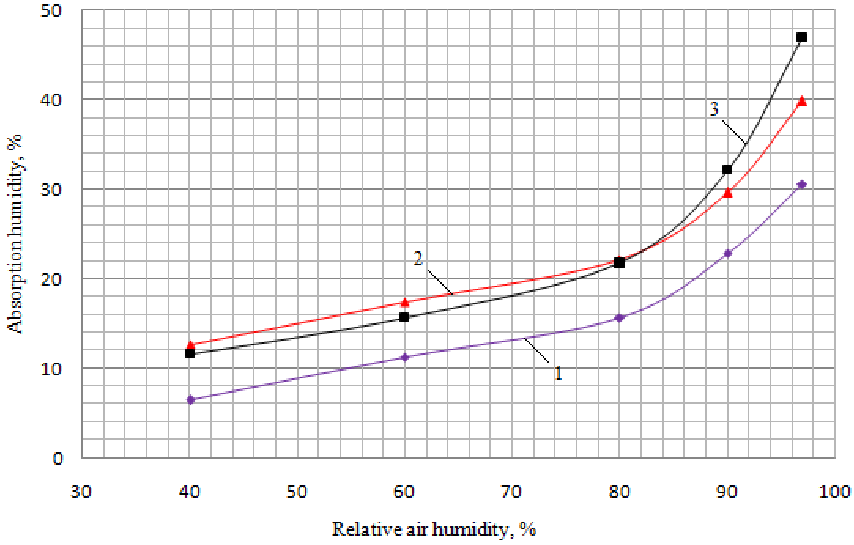
The absorption humidity of thermal insulation slabs was determined on samples having a quantitative composition, presented in Table 2.

Table 2. Quantitative composition and density of samples in the dry state.

No. of composition	Component consumption per 1 m^3, kg				Density, kg/m^3
	flax fibers	flax noils	polyester fiber	liquid glass	
1	29	-	5	-	34
2	60	-	-	10	70
3	-	60	-	10	70

According to the experimental data, the dependences of the materials absorption humidity on the relative humidity of the air in the form of absorption isotherms were constructed (Figure 3).

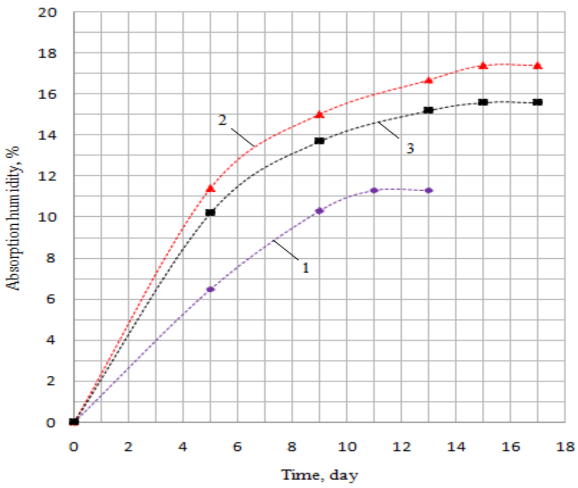
The analysis of the dependences obtained reveals that the absorption humidity of the «Akotherm flaks» material at an air humidity of 40% is lower than the flax fibers or flax noils slabs by 49% and 45%, respectively. Values of absorption humidity of flax fibers or flax noils samples are 54% more and in comparison with the insulation «Akotherm flaks» equal to 11.3% with a relative humidity of 60%. Maintaining the air humidity at 80% in a desiccator contributes to an increase in the «Akotherm flaks» material absorption up to 15.6%, which is 30% and 28% less than that of flax fibers and flax noils slabs. The relative air humidity of 90% causes an increase in the absorption humidity of flax and polyester fiber samples up to 22.9%, which is 29% lower than the value of the flax fibers or flax noils water vapor absorption. Regarding the indicators in the dry state, the absorption humidity of compositions 1, 2 and 3 samples at 97% air humidity is 31%, 40%, and 47%, respectively. At the same time, the absorption humidity content of the composition 1 slabs is less than that of the material of composition 2 by 24%, and samples of composition 3 by 35%.



1 – Akotherm flaks slabs; 2 – flax fiber slabs; 3 – flax noils slabs

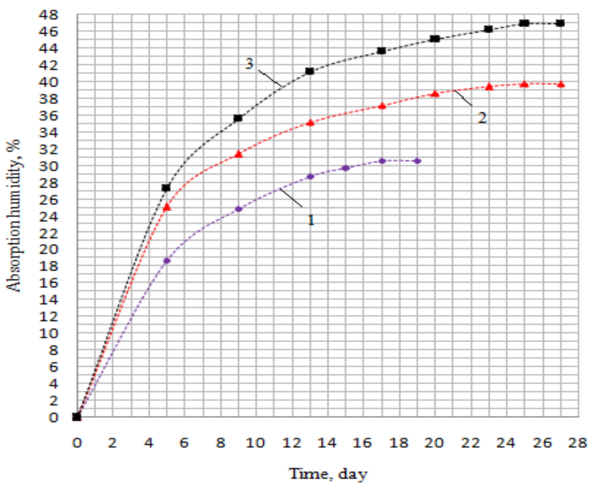
Figure 3. Water vapor absorption isotherms.

One more important characteristic for thermal insulation materials is water vapor absorption kinetics at a certain value of relative air humidity. As an example, figures 4, 5 show the water vapor absorption kinetics of samples taken from experimental insulation slabs at a relative humidity of 60% and 97%.



1 – Akotherm flaks samples;
2 – flax fiber samples;
3 – flax noils samples

Figure 4. Water vapor absorption kinetics at a relative air humidity of 60%.



1 – Akotherm flaks samples;
2 – flax fiber samples;
3 – flax noils samples

Figure 5. Water vapor absorption kinetics at a relative air humidity of 97%.

When air humidity is 40% for 9 days, the «Akotherm flaks» slabs absorption humidity reaches a value of 6.4%, which is 41% and 37% less compared to flax fibers and flax noils-based samples over the same period. Materials (compositions 2 and 3) acquire the maximum absorption humidity on the 13^{th} day, and it amounts to 12.6% and 11.6%, respectively.

Comparing the dependences in Figure 4 with a relative humidity of 60%, it is clear that the process of samples absorption (composition 1) ends on day 11 and is equal to 11.3%. This figure is 35% and 28% lower than that of compositions 2 and 3 slabs, respectively, with15 days water vapor absorption.

With air humidity of 80%, the absorption humidity of flax fibers and noils materials is almost the same. The water vapor absorption of samples (compositions 2 and 3) is intensively growing for the first 9 days and amounts to 20% and 19%, respectively, which is 49% and 43% higher than that of the composition 1slabs for the same period. «Akotherm flaks» material water vapor absorption ends on day 13 and is equal to 15.6%. The duration of flax fibers and flax noils samples absorption is 18 days, which is 5 days longer than that of the «Akotherm flaks» slabs. At the same time, the absorption humidity content of flax fibers and flax noils materials is 37% and 39% higher than that of the samples based on the mixture of flax and polyester fibers for the maximum absorption period.

The period of absorption humidity intensive growth (13 days) is typical of samples (compositions 1–3), kept at a relative humidity of 90%. It should be noted that during this period, the «Akotherm flaks» slabs absorption is 23%, which is 21% and 23% lower than that of flax fibers and flax noils samples. It is established that the maximum absorption humidity of flax fibers and noils-based materials for 22 days is 29% and 41% more than that of the «Akotherm flaks» slabs over 15 days.

Accelerated increase of water vapor absorption is characteristic of all samples at an air humidity of 97% for the first 13 days. At the same time, the indicator of flax fibers and flax noils absorption humidity content is 23% and 44% higher than that of the «Akotherm flaks» slabs. The process of water vapor absorption by flax and polyester fibers mixture samples ends on the 17th day, which is 8 days less than composition 2 and 3 materials. The values of «Akotherm flaks» samples absorption humidity are 22% and 44% lower than those of flax fibers and noils-based slabs. It should also be noted that at the end of water vapor absorption, the absorption humidity of flax fibers filler materials is 15% less compared to samples from flax noils. After absorption process completion, in all cases stabilization of water vapor absorption by the material is observed.

The further absorption process and the high absorption humidity of the material (composition 3) relative to the samples indicators (compositions 1 and 2) is due to the significant absorption humidity of flax noils. Separated elementary fibers in noils have a large geometrical contact area of the surface with the external environment in comparison with the indicator of flax fibers consisting of dense bundles of elementary fibers, this explains the results [20].

The lowest thermal conductivity of 0.08 W/(m·K) after a set of maximum absorption humidity is characteristic of the slab from flax noils. The thermal conductivity of the «Akotherm flaks» samples is almost the same, while the materials based on flax fibers exceed the indicators of the flax noils (composition 3) by 0.004 W/(m·K). The obtained thermal conductivity minimum coefficient of samples from flax fiber noils is achieved due to the multidirectional arrangement of elementary fibers in the insulation structure. This arrangement prevents the convective transfer of air by reducing the size of thin air spaces of irregular shape and their partial localization in the form of individual closed microcavities. Thus, in spite of the higher humidity content of flax noils slabs, the resulting structure of elementary fibers provides thermal conductivity identical with slabs based on flax and polyester fibers mixture.

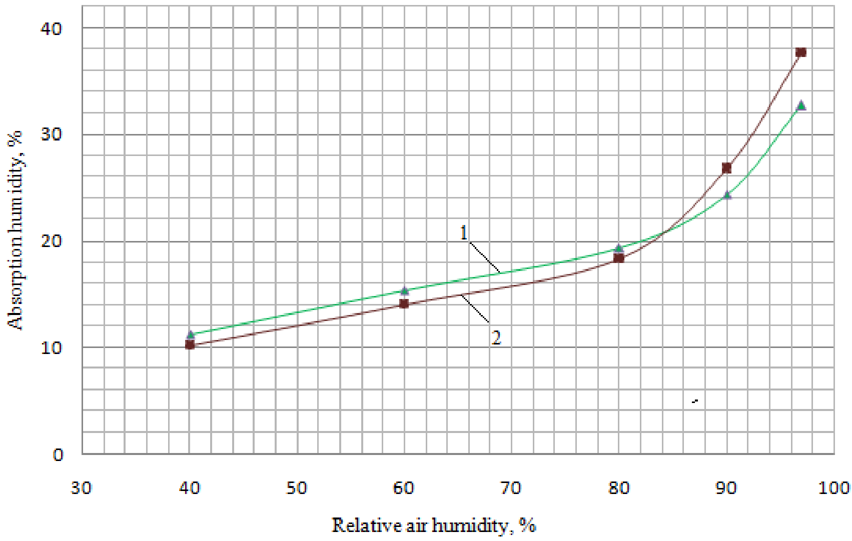
Additionally, studies have been conducted to determine the absorption humidity of sodium liquid glass and modified liquid glass in a dried state in a climatic chamber above water at a relative air humidity of 97%. Studies have shown that the rate of absorption humidity of the binder without additives reaches its maximum value of 19% after 9 days. The maximum humidity content of the modified liquid glass is 10% on day 7 at a temperature of +20 °C. Thus, it can be assumed that adding lime and gypsum to the binder will slow down the material's absorption of humidity from the air, as well as reduce the rate of water vapor absorption of fibers or noils-based samples due to a lower absorption humidity content of liquid glass with additives.

At the next stage, studies have been conducted to determine the absorption humidity of flax fibers or noils slabs with the use of a modified liquid glass. The quantitative composition and average density of the samples are presented in Table 3.

Table 3. Quantitative composition and density of samples in the dry state.

No. of composition	Component consumption per 1 m^3, kg					Density, kg/m^3
	flax fibers	flax noils	liquid glass	lime	gypsum	
1	60	-	9	0,5	0,5	70
2	-	60	9	0,5	0,5	70

According to test results, isotherms of water vapor absorption by experimental samples have been constructed (Figure 6). The experimental data obtained indicate that at a relative air humidity from 40% to 90%, the values of absorption humidity of flax fibers and noils samples at each air humidity indicator almost coincide. It should be noted that the addition of lime and gypsum to the binder at the indicated relative air humidity reduces the absorption rate of materials based on flax noils or fiber up to 5.4% relative to samples without additives. The relative air humidity of 97% contributes to an increase in the absorption humidity of thermal insulation materials with flax noils and modified liquid glass filler up to 37.6%, which is 13% higher than the value of water vapor sorption of flax fiber-based slabs. The use of lime and gypsum additives reduces the rate of absorption humidity of samples from flax fibers or flax noils by 18% and 20% compared with liquid glass-based slabs.



1 – flax fiber samples; 2 – flax noils samples

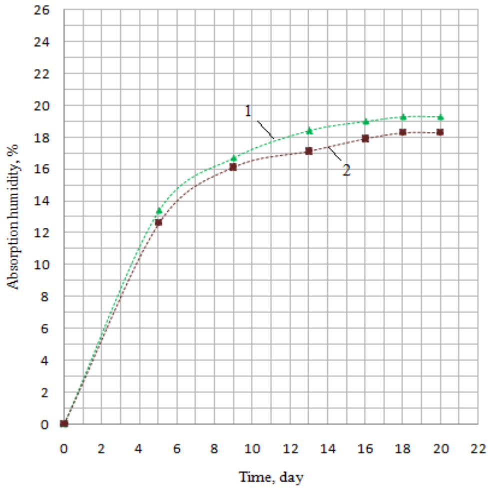
Figure 6. Water vapor absorption isotherms.

The water vapor absorption kinetics of the samples taken from experimental thermal insulation slabs at a relative air humidity of 80% and 97%is shown in Figures 7 and 8.

With relative air humidity of 40%, accelerated growth of absorption humidity in samples from flax fibers or noils is observed within the first 9 days. The indicator of flax-based slabs absorption humidity over a given period is equal to 9.9%, which is 10% more than that of the samples from flax noils. The water vapor absorption by the materials (compositions 1 and 2) lasts 13 days and reaches a maximum value of 11.2% and 10.2%, respectively.

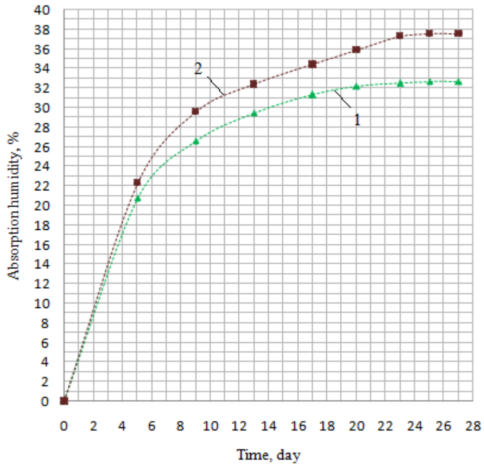
When the air humidity equals to 60%, the kinetics of absorption by samples has the same character as at a relative humidity of 40%. It is established that both materials absorb water vapor for 15 days. At the same time, the maximum value of the absorption humidity content of flax fiber slabs is 10% more than for samples based on flax noils (14%).

Intensive growth of the absorption humidity of thermal insulation materials from flax fibers or noils is preserved within the first 9 days and practically coincides with an air humidity of 80%. The duration of absorption is 18 days. The absorption humidity of the material (composition 1) and slabs (composition 2) is equal to 19.3% and 18.3%, respectively.



1 – flax fiber samples;
2 – flax noils samples

Figure 7. Water vapor absorption kinetics of the samples at a relative air humidity of 80%.



1 – flax fiber samples;
2 – flax noils samples

Figure 8. Water vapor absorption kinetics of the samples at a relative air humidity of 97%.

At a relative humidity of 90%, the accelerated water vapor absorption by materials (compositions 1 and 2) occurs in the first 13 days. It should be noted that the absorption humidity of the samples over a given time interval is almost the same and is equal to 23% and 24%, respectively. At the same time, the value of materials from flax noils is 10% higher than that of the slabs based on flax fibers for a maximum absorption period of 22 days.

The period of intensive growth of absorption humidity of 13 days is also characteristic for air humidity of 97%. The absorption of water vapor by flax noils samples for a given period is 32.4%, which is 10% more than that of flax fiber-based slabs. The process of absorption of materials ends on the 25th day. The maximum value of the absorption humidity of the samples (composition 2) is 37.6%, and for materials of composition 1, it is 13% less and amounts to 32.7%.

According to the results of studies, it has been established that the use of modified liquid glass does not affect the duration of the water vapor absorption process by experimental thermal insulation materials, but at the same time it reduces the absorption humidity of samples based on flax fibers or noils. For example, at a relative air humidity of 97%, the introduction of additives from lime and gypsum leads to a decrease in the value of the absorption humidity content of samples from flax fibers or flax noils by 18% and 20%, respectively, relative to slabs with liquid glass without modifiers.

The thermal conductivity coefficient of samples from flax fibers or flax noils on a modified liquid glass in a wet state is 0.079 W/(m·K) and 0.073 W/(m·K), respectively. As a result, the thermal conductivity of slabs using liquid glass with a maximum humidity of 0.005–0.007 W/(m·K) is higher than the thermal conductivity of the samples due to binding with lime and gypsum additives. Reduction of flax noils slabs thermal conductivity is achieved by introducing modified additives that increase the insolubility of liquid glass under the action of humidity vapor from the air. The insolubility of the binder reduces the absorption of humidity from the air by the liquid glass and thus reduces the absorption humidity of thermal insulation slabs. As a result, the reduction of the composite thermal conductivity under operating condition is observed.

IOP Conf. Series: Materials Science and Engineering **660** (2019) 012072 doi:10.1088/1757-899X/660/1/012072

4. Conclusions

According to the experiment results, it has been found out that at a relative air humidity of 97%, the absorption humidity of samples based on flax fibers or flax noils is 39.8% and 46.9%, which exceeds the value of the «Akotherm flaks» slabs (30.6%) by 30% and 53% respectively. The introduction of additives from lime and gypsum into the binder can reduce the absorption humidity of flax fibers or flax noils-based slabs by 18% and 20% to 32.7% and 37.6%.

It has also been established that a change in the humidity index has a significant effect on the thermal conductivity of slabs from flax fibers or flax noils. The maximum humidity content of thermal insulation materials based on flax fibers leads to an increase in the thermal conductivity coefficient from 2 to 2.3 times relative to samples in a dry state. Lowering the absorption humidity due to the introduction of modified liquid glass allows reducing the thermal conductivity of thermal insulation materials from flax fibers at an increased relative air humidity by 0.0057–0.007 W/(m·K) relative to slabs that do not contain lime and gypsum additives.

The obtained data on the kinetics of water vapor absorption by insulating slabs make it possible to calculate the humidity conditions of the structure. Also, the experimental data will be used in the development of a predictive model of changes in the thermal performance of insulation during the operation of buildings and structures.

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