

Relationship between operational properties of peat heat-insulating materials and the content of mineral binders in them

Anton Sinitsyn^{1,*}, Ludmila Voropay¹, Regina Salikhova² and Olga Yukhtarova¹

¹Vologda State University, Lenina str. 15, 160000, Russia

²Kazan State Power Engineering University, Kazan, Russia

Abstract. This work presents the main results of calculation and experimental study on relation between the operational properties of peat heat-insulating materials (HIM) and the content of mineral binders in them aiming at reducing heat energy costs by energy-consuming objects. It was experimentally proved that introduction of cement increases thermal conductivity, and introduction of calcium oxide as a mineral binder, on the contrary, promotes the development of material porosity while maintaining strength characteristics and elasticity and helps to reduce the thermal conductivity and specific density. The established relationship between the content of calcium oxide and the thermal conductivity enables modelling of technology for HIM producing based on peat and inorganic binders.

1 Introduction

The President and the Government of the Russian Federation have set a strategic task to determine ways to rationally use the country's most important national treasure – natural energy resources. Currently, the policy of energy and resource conservation is one of the priority economic directions for the entire national economy. Reducing the energy consumption of residential and public buildings, various industrial facilities will create conditions for increasing the efficiency of use of fuel, energy, material resources during production of heat and electricity, a wide range of industrial, transport and construction products [1-7].

To reduce energy costs and create comfortable conditions for the use of buildings, a set of measures is used. It includes the use of high-quality environmentally friendly new types of heat-insulating materials obtained on the basis of available natural raw materials or unclaimed plant waste products (wood waste). Peat composite materials are of great practical interest in the modern market of heat-insulating materials. It is known that peat plates made from different types of peat with introduction of wood waste and mineral binders are characterized by thermal conductivity in the range 0.04-0.065 W/m·K, which meets the requirements of the Russian State Standards. The introduction of mineral components increases the prism strength together with thermal conductivity. Therefore, when choosing a chemical composition during production of heat-insulating materials (HIM), it is necessary to establish a relationship between the thermal conductivity and the content of mineral binder. It is also known that heat-insulating plates produced without addition of inorganic binders have low thermal conductivity, but at the same

time low fire resistance, biostability, and temperature resistance, which are significant disadvantages.

In this regard, to increase the strength characteristics, fire resistance, biostability while obtaining thermal conductivity, almost equal to that of air, it is necessary to introduce mineral additives into peat, for example, cement, and limestone.

It is known that introduction of mineral binders in a peat mixture increases thermal conductivity and specific density of materials by reducing porosity. However, formation of a porous structure depends on the amount of mineral binders introduced into the peat mixture, for example, cement and quicklime (calcium oxide).

The aim of this work is to experimentally establish the relationship between thermal conductivity and the amount of cement or calcium oxide introduced into the peat mixture.

To achieve this aim, the following tasks were solved:

1. To perform a patent search on the specified topic; to produce samples using the known technologies in laboratory conditions, and to determine their thermal conductivity, specific density, prism strength.

2. To analyze the obtained results.

3. To experimentally determine the relationship between the amount of cement or calcium oxide introduced into the peat mixture and the operational characteristics of the obtained HIM.

4. To choose the optimal amount of inorganic components introduced into peat based on the obtained experimental results.

5. To produce model samples of HIM using new technology and examine their performance characteristics.

The object of study is the operational characteristics of composite peat heat insulators. The subject of study is

* Corresponding author: sinitsyn.science@mail.ru

Table 1. Chemical characteristics of the high-lying peat of the Vologda region.

Sample No.	Field	Peat type	Peat kind	Degree of decomposition, %	Ash-content, %	Content of organic substances, %	pH
1	Vologodskoe	High-lying	Pine-cottongrass	20.0	11.68	88.32	6.0
2				20.0	11.78	88.22	6.0
3				20.0	11.86	88.14	6.0
4				20.0	11.87	88.13	6.0

the relationship between the amount of mineral additives and the thermal conductivity.

The work was carried out in the REC “Problems of the modern technological environment”. The similar works performed by the REC can be found in previous publications, for example, in [8-10].

2 Methods

During the experiment, the following methods were used: gravimetric, titrometric, combustion technique, stationary heat flow technique, compressive strength test, densimetric technique.

At the first stage of study, samples of heat-insulating materials were obtained using the known technologies. The high-lying peat taken from the peat deposit of the Vologda region was used as a heat carrier. In laboratory conditions, the chemical characteristics of peat were determined from its combustion: ash content, organic matter content in accordance with the Russian State Standards GOST 27784-88 [11] and GOST 26213-91 [12]. Samples were calcined in a muffle furnace SNOL-7-2/1100 at a temperature of 350-400 °C. The resulting solid precipitate was weighed on analytical balance and the ash content was calculated according to the following expression (1):

$$A = \left((m - m_1) / m_2 \right) \cdot 100, \% \quad (1)$$

where A is the ash content, %; m is the mass of crucible with ash residue, g; m_1 is the mass of the empty crucible, g; m_2 is the mass of dry soil, g.

The content of organic substances was determined from ash-content according to formula (2):

$$X = (100 - A), \quad (2)$$

where A is the ash content, %.

The chemical characteristics of four peat samplings are presented in Table 1.

It is known that during HIM production peat acts not only as a heat insulator, but also as a framing, which forms a certain structure of the composite mixture after introduction to peat of additives (wood sawdust), inorganic cement or calcium oxide, and organic binder - hardener.

3 Results

The previous studies performed at Vologda State University experimentally proved that high-lying peat forms a more porous structure compared to that of low-lying peat. So, the resulting composites of different content always have lower thermal conductivity - 0.045-0.065 W/m·K, higher elasticity, lower specific density of 170-260 kg/m³ while maintaining the prism strength not more than 0.3 MPa, which meets the requirements of the Russian State Standard GOST.

The performed patent search showed that cement is widely used as an additive to peat, and it is added to a mixture of high-lying peat and wood waste [13]. The following optimal composition of mixture was determined experimentally: 12% phr of high-lying peat, 38% phr of Portland cement, 25% phr of wood waste, 22% phr of water. The high-lying peat with a decomposition degree of 5–10% and a moisture content of 55–70% is used. According to the technology, it together with wood waste is soaked in solution containing methanol in the amount of 6–10 mg/l at a temperature of 80–100 °C for 2–5 min. This technology enables obtaining heat-insulating plates that have compressive strength of 6.41 MPa, and thermal conductivity of 0.18 W/m·K, which does not meet the requirements of the Russian State Standard GOST and exceeds the allowable thermal conductivity by 4 to 5 times.

Thus, the introduction of Portland cement contributes to an increase in mechanical strength, resistance to water and biological damage, which is an advantage of this technology. However, the specific density also sharply increases to 920 kg/m³ and, as mentioned above, the thermal conductivity increases above the permissible values, which limits application of this technology. The lack of technology itself should also be noted. The feasibility of using a water-methanol mixture for soaking sawdust is questioned, and this process is carried out at a temperature of 80 - 100 °C, which significantly exceeds the methanol boiling point. Therefore, at this temperature, methanol evaporates and enters the environment. To eliminate the negative impact of methanol, which belongs to the first class of toxicity, there is a need to install an additional ventilation system.

In recent years, cement cyclone dust (cement production wastes) have been used as fillers, which is added to a suspension of organic binder - polyvinyl acetate - and the suspension is introduced into cut peat

Table 2. Composition of the initial heat-insulating mixture.

Sample No.	The initial mixture composition				
	High-lying peat (wet), %	Sawdust, %	Wood powder, %	Cement, %	Polyvinylacetate polymer, %
1	72	-	-	14	14
2	72	-	-	14	14
3	72	-	-	14	14
4	62.5	12.5	-	12.5	12.5
5	62.5	12.5	-	12.5	12.5
6	62.5	12.5	-	12.5	12.5
7	62.5	-	12.5	12.5	12.5
8	62.5	-	12.5	12.5	12.5
9	62.5	-	12.5	12.5	12.5

[14]. However, the introduction of cyclone dust alone does not provide high mechanical strength of HIM, and therefore it is always recommended to add Portland cement as a supplementary material.

In laboratory conditions, HIM samples with addition of cyclone dust were obtained. The following chemical composition is maintained: 28% phr of cement, 52% phr of peat modified with a suspension of polyvinyl acetate and cyclone dust, 20% phr of water.

After thorough mixing, molding and holding in air, heat-insulating plates are obtained that have the following characteristics: specific density of 400 kg/m³, compressive strength of 1.5 MPa, thermal conductivity of 0.1 W/m·K. Thus, with an increase in peat content and due to the impregnation of peat with polyvinyl acetate and cyclone dust, the uniformity of the structure and the durability of heat-insulating materials increase. However, the introduction of peat cement in amount of 28% contributes to an increase in thermal conductivity and specific density of material.

To increase the material porosity, the authors [13] propose to introduce sodium carbonate in addition to Portland cement and cyclone dust. The introduction of sodium carbonate as an additive helps to reduce the specific density of HIM while maintaining its strength characteristics. However, it was experimentally established that the porosity of material, which governs its heat-insulating properties, is determined by the medium pH and the processing temperature. If the

medium pH is more than 7, that is, the medium is alkaline, so under these conditions it is necessary to heat the insulating mixture to the decomposition temperature of sodium carbonate, which is a significant drawback of this technology. In addition, the use of sodium carbonate to create porosity in the amount of 10% of the total mass of heat-insulating mixture increases the material costs, which reduces competitiveness of this technology in the HIM market.

Also HIM samples were obtained with the addition of cement with lower concentrations. The mixture composition is presented in table 2.

To obtain more accurate results, each experiment was repeated 3 times. The main HIM characteristics are derived from the average of three measurements. Physico-mechanical characteristics of HIM are presented in table 3.

The results show that the introduction of wood filler in the form of sawdust and powder into the samples promotes reduction of thermal conductivity and specific density. At the same time, replacing wood sawdust with wood powder results in higher values of these parameters.

The results indicate that introduction of Portland cement increases the thermal conductivity and reduces the porosity of material at minimum concentration of this binder. Therefore, it can be concluded that the use of cement in production of heat-insulating materials is not always advisable and it is better to use mineral binders

Table 3. Physico-mechanical characteristics of insulating samples.

Sample No.	Physico-mechanical characteristics		
	Density, kg/m ³	Thermal conductivity, W/m·K	Mechanical strength, MPa
1	1238	0.533	4.64
2			
3			
4	657	0.232	1.67
5			
6			
7	758	0.283	2.92
8			
9			

Table 4. Composition of thermal insulation mixture for HIM production.

Composition of thermal insulation mixture	Sample No.		
	1	2	3
High-lying peat (with preserved natural structure), %	40	50	60
Wood powder, %	20	15	10
Calcium oxide (CaO), %	20	15	10
Polyvinylacetate polymer, %	15	15	15
Water, %	5	5	5

that provide greater porosity of heat insulator structure, for example, quicklime (calcium oxide).

Unlike cement, when calcium oxide is introduced into wet peat, a more uniform porous structure with small inclusions from peat and sawdust is formed, which contributes to a decrease in thermal conductivity and specific density of HIM while maintaining their strength characteristics.

At the next stage of the study, the optimal composition for obtaining HIM based on peat, calcium oxide, wood powder and an organic binder - polyvinyl acetate polymer was established.

A series of samples were made according to the composition shown in table 4.

Water is added to the high-lying peat for moisturizing and, after the peat has been completely saturated with water, calcium oxide obtained by calcining the limestones is added. After thorough mixing, wood powder is added and organic hardener is introduced. After mixing, the mixture is placed in the molds of 150×150×40 mm, the mass is compacted with a press, and the mixture setting conditions (setting time and temperature) are selected. Next, the obtained samples are cooled and tested in laboratory conditions to determine their average density, compressive strength, thermal conductivity. The research results are presented in table 5.

While determining the relationship between thermal conductivity and the content of calcium oxide, it was found that addition of calcium oxide does not increase the thermal conductivity above the requirements of the Russian State Standard GOST. At the same time, the dependence of structure formation on temperature is also noted. It was found that when a heat-insulating composition is heated to 105 °C in order to remove free water, a porous structure is first formed, which undergoes cracking upon slow cooling. The sample subjected to heat treatment at a temperature of 105 °C is shown in Figure 1.



Fig. 1. The sample subjected to heat treatment at 105 °C.

Therefore, it is not recommended to heat the mixture to a temperature of 105 °C. A firm homogeneous finely porous structure forms at a temperature of 95-100 °C and at a setting time of 16 hours.

The thermal conductivity is evaluated using the device ITS-1 "150".

The measurements of thermal conductivity are based on the stationary heat flux method according to the requirements of the Russian State Standard GOST 7076-99 [15]. The obtained thermal conductivity is presented in Figure 2.

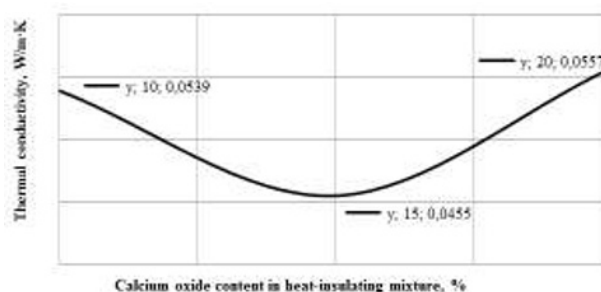


Fig. 2. Relationship between thermal conductivity and calcium oxide content in heat-insulating mixture.

Table 5. Physico-mechanical characteristics of HIM.

Physico-mechanical characteristics	Sample No.		
	1	2	3
Average density, kg/m ³	482	457	461
Thermal conductivity, W/m·K	0.0557	0.0455	0.0539
Compressive strength, MPa	1.65	1.38	1.42

The experimental results also prove the dependence of thermal conductivity on the content of calcium oxide. With an increase in the content of calcium oxide in mixture from 10 to 15%, a decrease in thermal conductivity from 0.0539 to 0.0455 W/m·K is observed. With an increase in the content of calcium oxide in mixture from 15 to 20%, an increase in thermal conductivity from 0.0455 to 0.0557 W/m·K is observed.

The established relationship between the content of calcium oxide and the coefficient of thermal conductivity allows one to model the HIM production technology and to obtain samples with certain specified performance characteristics.

At the same time, the specific density and prism strength of the obtained samples were determined. Prism strength and specific density were determined in accordance with the requirements of the Russian State Standard GOST 17177-94 [16]. The results on average density are presented in Figure 3.

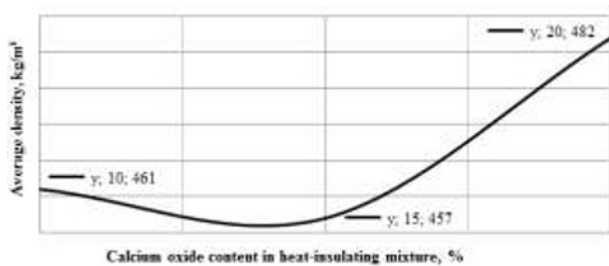


Fig. 3. Relationship between average density and calcium oxide content in heat-insulating mixture.

Analysis of results shows that with an increase in the content of calcium oxide from 10 to 15%, the average density of samples decreases from 461 to 457 kg/m³. On the contrary, with an increase in calcium oxide from 15 to 20%, an increase in the average density of samples from 457 to 482 kg/m³ is observed. The minimum average density is typical for samples containing 15% of calcium oxide in the initial composite mixture. The studies of mechanical strength are presented in Figure 4.

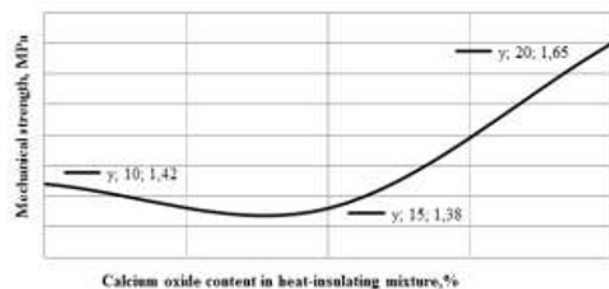


Fig. 4. Relationship between mechanical strength and calcium oxide content in heat-insulating mixture.

The obtained data indicate that with a decrease in the content of calcium oxide, the compressive strength decreases. Maximum strength is typical for samples with calcium oxide content in the composite mixture of 20%.

It was concluded that the optimal composition of HIM with introduction of calcium oxide is as follows: 50% of horse peat (with a preserved natural structure);

15% of wood powder; 15% of calcium oxide; 15% of polyvinyl acetate polymer; 5% of water.

4 Conclusions

Thus, based on the obtained experimental data, the following conclusions can be drawn:

1. It has been experimentally proved that introduction of cement contributes to an increase in thermal conductivity. The introduction of calcium oxide as a mineral binder, on the contrary, contributes to the development of material porosity while maintaining strength characteristics and elasticity and helps to reduce the thermal conductivity and specific density.

2. The established relationship between the content of calcium oxide and the thermal conductivity allows one to model the HIM production technology based on peat and inorganic binders and to obtain samples with certain specified performance characteristics.

3. The optimal composition of HIM was experimentally selected, which provides consumer properties of the composite that meet the requirements of the Russian State Standard GOST.

4. HIM model samples were fabricated using new technology and their operational characteristics were investigated.

References

- [1] L.V. Larchenko, R.A. Kolesnikov, L. Mukhametova, Russian oil and gas industry as a sphere of international interests and economic cooperation, E3S Web of Conferences **161**, 01006 (2020).
- [2] V. Markov, A. Feduyukhin, I. Sultanguzin, B.G. Matisov, N.V. Nikitkov, V.V. Izrantsev, V.G. Knorring, G.A. Konrashkova, L.R. Mukhametova, Improvement of energy efficiency of motor fuel production at oil refinery, IOP Conference Series: Earth and Environmental Science **337**, 1, 012080 (2019).
- [3] L.R. Mukhametova, I.G. Akhmetova, A.V. Fedukhin, S.O. Makoev, A.A. Kalyutik, About heat supply schemes for settlements and city districts, IOP Conference Series: Earth and Environmental Science **288**, 1, 012108 (2019).
- [4] I. Akhmetova, A. Tyfetylov, A. Tamakchi, G. Khadiyllina, O. Derevianko, Z. Syed, Improving the competitiveness of automobile engineering enterprises by advancement the internal control over its indicators, International Journal of Civil Engineering and Technology **9**, 13, 1865-1876 (2018).
- [5] A.A. Kalyutik, D.V. Grigorieva, A.V. Feduyukhin, O.V. Derevianko, I.G. Akhmetova, Reduction of the technological minimum by bypass method with environmental impact estimation on the example of energy blocks with T-100 and T-250/300-240 turbines, IOP Conference Series: Earth and Environmental Science **288**, 1, 012094 (2019).

- [6] V.I. Sitas, A.V. Fedyukhin, I.G. Akhmetova, A. Mitrofanov, S.O. Makoev, A. Asadpoori, A.A. Sinitsyn, E.A. Kikot, Assessment of technical and economic efficiency indicators of cogeneration in modern market conditions, *International Journal of Civil Engineering and Technology* **10**, 2, 2106-2117 (2019).
- [7] E. Sukhareva, A. Fedyukhin, O. Derevianko, M. Egorov, L. Mukhametova, I. Akhmetova, Optimization of combined heat and power plant operating mode by means of underutilized equipment mothball, *IOP Conference Series: Earth and Environmental Science* **288**, 1, 012122 (2019).
- [8] D.F. Karpov, M.V. Pavlov, A.A. Sinitsyn, Experimental Research of the Thermal Balance of Loose Disperse Materials Exemplified by Milled Peat Exposed to Infrared Heating, *Vestnik MGSU* **5**, 114-119 (2012).
- [9] D.F. Karpov, M.V. Pavlov, A.A. Sinitsyn, Solution to the Boundary Problem of Heat and Water Transmission in a Layer of a Loose Disperse Material Exemplified by Milled Peat Exposed to Infrared Heating, *Vestnik MGSU* **6**, 92-98 (2012).
- [10] A.A. Sinitsyn, Experience of Small Innovative Enterprises Foundation in the Vologda Region, *Middle East Journal of Scientific Research* **16**, 10, 1424-1427 (2013).
- [11] The Russian State Standard GOST 27784-88, *Soils, Method for determination the ash content of peat and peat soil horizons* (Standards Publishing House, 1988).
- [12] The Russian State Standard GOST 26213-91, *Soil, Methods for determination of organic matter* (Standards Publishing House, 1992).
- [13] A.Yu. Tarakanov, O.A. Medvedev, *Peat-polymer mixture for producing heat-insulating products*, Patent 2555180 Russian Federation, MPK S 04 V 38/08, applicant and patent holder All-Russian Research Institute for Civil Defense and Emergencies EMERCOM of Russia, 2014116521/03, declared 24.04.2014, publ. 10.07.2015, bull. no. 19.
- [14] O.A. Medvedev, L.B. Khoroshavin, V.S. Rudnov, et al., *Peat-polymer mixture for producing heat-insulating products with increased fire resistance*, Patent 2513801 Russian Federation, MPK⁽⁵¹⁾ S 04 V 26/00, applicant and patent holder All-Russian Research Institute for Civil Defense and Emergencies EMERCOM of Russia, 2012147661/03, declared 09.11.2012, publ. 20.04.2014, bull. no. 11.
- [15] The Russian State Standard GOST 7076-99, *Method for determination of thermal conductivity and thermal resistance under stationary thermal conditions* (Standards Publishing House, 2000).
- [16] The Russian State Standards GOST 17177-94, *Heat-insulating materials and products, Research methods* (Standards Publishing House, 2002).