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Stability of Thermal Insulation Properties of Basalt Thermal Insulation

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Abstract: Reducing heat losses during the transportation of heat carriers is one of the most important tasks for improving the energy efficiency of heat supply. Thermal insulation made of rock wool is widely used for insulation of high-temperature equipment and pipelines transporting hot water and steam. In the manufacture of thermal insulation, manufacturers use various polymer binders to bond fibers. However, high temperatures of insulated surfaces lead to thermal decomposition of the polymer binder, which can lead to a decrease in the thermal insulation properties of materials and an increase in heat loss during operation. The paper examines the change in the coefficient of thermal conductivity of basalt thermal insulation during thermal degradation of a polymer binder. A series of experiments was conducted. at which the temperature on the surface of the heater was maintained at 100 °C, 200 °C, 300 °C, 400 °C. Measurements were carried out on the samples before heat treatment, as well as after heat treatment in a furnace at 650 °C for 12 hours. It is shown that during the thermal degradation of the binder, the coefficient of thermal conductivity increases by 20%. It also shows how the arrangement of fibers in the material affects the increase in thermal conductivity. According to the results of the thermogravimetric analysis, it is shown that in the temperature range from 240 °C to 650 °C, the binder completely decomposes. It is shown how the thermal decomposition of the binder increases the water absorption of basalt thermal insulation.

1 INTRODUCTION

One of the directions in increasing the energy efficiency of heat supply is to reduce heat losses during the transportation of heat carriers, which is impossible without the use of effective thermal insulation materials. In 2023 in the Russian Federation 1 287 million Gcal of thermal energy was supplied to heating networks. Reducing heat losses by even 1% of the heat released in the grid will save 12,87 million Gcal of heat energy or 1,8 million tons of conditional fuel. The industry of the Russian Federation consumes up to half of the total heat energy produced. It is also necessary to take into account that centralized heat supply prevails in the Russian Federation, and the length of pipelines of heating networks is significant (168 thousand kilometers). During the transporting hot water, the temperature of the coolant can reach 150 °C, when transporting steam – up to 600 °C. In this regard, there are quite significant losses of thermal energy during the transportation of heat carriers.

Rock wool is widely used in industry, for insulation of equipment, as well as in heating networks for insulation of pipelines during transportation of steam and hot water. The widespread use of these materials is explained by the wide temperature range of application, as well as the low cost of these materials. Temperatures of surfaces insulated with these materials can reach 600 °C. However, high temperatures of insulated surfaces can negatively affect the stability of thermal insulation properties during operation.

Thermal insulation made of rock wool belongs to the group of inorganic thermal insulation materials. Basalt fiber obtained from molten rocks of the gabbro-basalt group is used in the manufacture of thermal insulation products. The basalt fiber has a

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high temperature resistance up to 1000 °C (Siligardi et al., 2017; Gualtieri et al., 2009). Various thermal insulation products are made of rock wool – plates, mats, cylinders, etc. Thermal insulation products made of rock wool can be made with or without a binder. If a superfine basalt fiber with a fiber diameter of 1-3 microns is used, then the product in the form of a mat can be made without the use of a binder.

Plates, as well as cylinders and semi-cylinders are made using a binder. The binder serves to bond the fibers, as well as increase the strength and rigidity of the product, reduces the hygroscopicity of the product and reduces dust formation. Various organic substances based on phenol-formaldehyde resins, carbamide resins, etc. are used as binders.

In practice, rock wool with a binder is often used to insulate pipelines transporting steam and hot water. Manufacturers of thermal insulation materials also claim that rock wool with a binder can be used at temperatures of insulated surfaces up to 450 °C.

However, we want to show that high temperatures of the insulated surfaces lead to thermal degradation of the binder. The thermal degradation of the binder begins at temperatures of 240 °C. At 650 °C, the binder completely decomposes. And when using rock wool with a binder, heat losses during operation may increase. The annual reports of the Russian Ministry of Energy indicate an increase in heat losses in heating networks (REA Ministry of Energy of Russia).

The introduction of new materials, such as aerogel insulation, into operation in the Russian Federation is not widespread and is occurring at an extremely slow pace due to the lack of a broad production base in the Russian Federation and the correspondingly high cost of such materials (Yang et al., 2025; Lakatos et al., 2025; Yan et al., 2021; Gao et al., 2023)

The paper studies the change in the thermal conductivity coefficient of basalt thermal insulation during thermal destruction of the polymer binder.

2 MATERIALS AND METHODS

2.1 Materials

The researches were conducted on thermal insulation products made of basalt fiber with a polymer binder. Thermal insulation cylinders are manufactured using a binder only. Cylinders can be made in different ways – by winding, pressing or cutting. The manufacturing method affects the location of the basalt fiber in the material, and this in turn affects the technical characteristics. For the experiments, three samples of basalt thermal insulation cylinders, produced by the cut-out method, with a density of 100 kg/m^3 were selected. The study was also conducted on flat samples. For this purpose, three samples of basalt thermal insulation boards with a density of 50 kg/m^3 were selected. In the production of which manufacturers also use a polymer binder to bond the fibers. The content of polymer binder in the studied samples was 5% by weight. A study was also conducted on samples of basalt superfine insulation without binder.

2.2 Study of changes in thermal conductivity coefficient

Thermal conductivity of cylindrical products was measured in accordance with GOST 32025 “Thermal insulation. Method for determining heat transfer characteristics in factory-made cylinders in a steady-state thermal mode.” This Russian standard is largely based on ISO 8497 “Thermal insulation. Determination of steady-state heat-transfer properties of thermal insulation for round pipes” (GOST 32025). The authors of this work created an experimental setup, the description of which is given in (Vankov, Bazukova et al., 2022).

The study of thermal conductivity of fibrous thermal insulation materials using the stationary thermal regime method on flat samples was carried out in accordance with GOST 7076-99. The specified Russian standard is harmonized with ISO 7345 and ISO 9251 standards in terminology and corresponds to the main provisions of ISO 8301, ISO 8302 standards, which establish methods for determining thermal resistance and effective thermal conductivity using a device equipped with a heat meter and a device with a hot safety zone (GOST 7076). The authors of this work created an experimental setup, the description of which is given in (Vankov, Bazukova et al., 2022).

To research the change in the thermal conductivity coefficient of thermal insulation made of basalt fiber with a polymer binder, the samples were subjected to heat treatment in a furnace. The furnace used is capable of maintaining a constant temperature throughout the volume in the range of 100-1000 °C. The samples were subjected to heat treatment in an oven at a constant temperature for 12 hours. The samples were then cooled naturally to room temperature. The thermal conductivity coefficient was measured before and after heat treatment in the furnace.

2.3 Thermal stability study

Thermogravimetric analysis (TG analysis) was used to study the thermal stability of the samples. TG analysis is widely used to study the processes of thermal degradation. Thermogravimetric analysis was performed on the equipment of TG209F1 Libra (Netzsch GmbH).

2.4 Water absorption study

Heat losses during humidification of thermal insulation can increase several times compared to pipelines with dry thermal insulation (Polovnikov, 2018; Ochs et al., 2022).

The water absorption of the basalt thermal insulation cylinder samples was determined by short-term complete immersion of the samples in water. The samples are placed in a container with water for 24 hours. The mass of water absorbed by a sample of dry material is measured when fully immersed in water for 24 hours.

3 RESULTS AND DISCUSSION

Samples of thermal insulation materials were subjected to heat treatment in a furnace to achieve varying degrees of binder burnout. During heat treatment in an oven at a constant temperature of 250 °C for 12 hours, the degree of thermal degradation of the binder was 0,2. During heat treatment at a constant temperature of 380 °C for 12 hours, the degree of thermal degradation of the binder was 0,6. After heat treatment in an oven at 650 °C for 12 hours, the binder completely burned out. The appearance of the samples before and after the isothermal treatment in the furnace is shown in figure 1.

Figure 1: The appearance of samples of basalt thermal insulation cylinders after heat treatment in a furnace. From left to right: a new sample; after 12 hours at 250 °C (20% of the binder burned out); after 12 hours at 350 °C (60% of the binder burned out); after 12 hours at 650 °C (binder completely burned out).

Figure 2 shows the change in the thermal conductivity coefficient of basalt thermal insulation cylinders depending on the average temperature in the material layer. A series of experiments were conducted in which the temperature on the surface of the heater was maintained at 100 °C, 200 °C, 300 °C, 400 °C. The average temperature in the material layer was determined as the arithmetic mean of the temperatures on the front faces of the test sample. Measurements were taken on samples before heat treatment and after heat treatment in a furnace at 650°C for 12 hours. After heat treatment at 650°C, the polymer binder that holds the fibers together burns out completely.

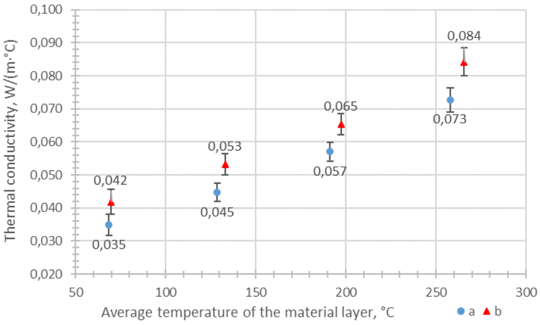

Figure 2: Change in the thermal conductivity coefficient of basalt thermal insulation cylinders depending on temperature: a – samples before heat treatment; b – samples after heat treatment in a furnace at a temperature of 650 °C for 12 hours.

The external appearance of the samples before and after heat treatment is shown in Fig. 3. The binder used to bond the fibers increases the rigidity and strength of the product, reduces hygroscopicity, and prevents dust formation. After the binder burns out, loosening of the material is characteristic, the shape of the product is deformed (Fig. 3).

Figure 3: Samples of basalt thermal insulation cylinders before (left) and after heat treatment (right).

When exposed to loads, the material layer becomes compacted and the thickness of the heat-insulating layer decreases. After the binder burns out, the thermal conductivity coefficient increases by 20%.

The location of the fibers in the material also affects the technical characteristics of the product. Thus, if the thermal insulation cylinder is made by the cut-out method, then the fibers in the material are arranged randomly, some of the fibers are parallel to the heat flow, some perpendicular. Since thermal insulation made of rock wool belongs to the class of fibrous thermal insulation materials, the structure of the material is a solid skeleton formed by basalt fibers, with an air layer (pores and capillaries) in the space between the fibers. If the air gap between the fibers is located parallel to the heat flow, this increases the coefficient of thermal conductivity of the material, if perpendicular, it decreases. If the binder burns out, the volume of through pores and capillaries increases, including those located parallel to the heat flow. In this case, convective heat exchange intensifies and the effective thermal conductivity of the material increases.

Experiments were also conducted with basalt slabs with a density of 50 kg/m^3. Measurements were carried out on samples before heat treatment, as well as after heat treatment in a furnace at 650 °C for 12 hours. After heat treatment at 650 °C, the polymer binder that binds the fibers completely burns out. The appearance of the samples before and after heat treatment in the furnace is shown in Figure 4.

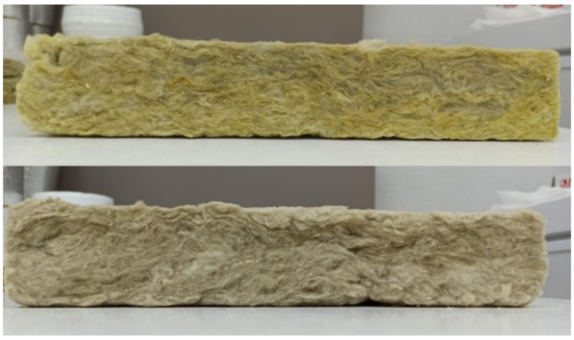

Figure 4: Samples before (upper) and after (lower) heat treatment in the furnace.

The plates are dominated by the horizontal arrangement of fibers, as well as air pores and capillaries, perpendicular to the heat flow. After the binder burns out, the loosening of the material is noticeable. When the material is loaded, it is compacted. A metal plate was placed on the sample, creating a load of 500 Pa. Figure 5 shows the change in the coefficient of thermal conductivity of basalt fiber thermal insulation boards when exposed to a 500 Pa load on the material before and after heat treatment in the furnace.

Although Figure 5 shows that the change in thermal conductivity before and after burnout of the binder for a material with horizontal fiber arrangement is insignificant and is within the error limits. However, after heat treatment in the furnace, the binder is completely burnt out, and the applied load of 500 Pa leads to a decrease in the thickness of the product from 50 mm to 43 mm. For samples before heat treatment in the furnace, there is no decrease in the thickness of the product at a load of 500 Pa. When exposed to a load of 500 Pa, the thermal resistance of the sample decreased from 0,77 to 0,68 (m$^{2}\cdot{}^{o}$C)/W.

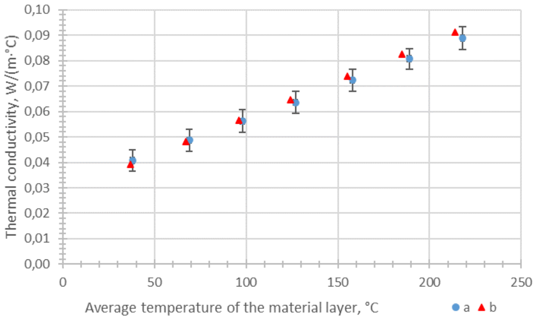

Figure 5: Change in the thermal conductivity coefficient of basalt thermal insulation boards depending on temperature, under a load of 500 Pa: a – samples before heat treatment; b – samples after heat treatment in a furnace at a temperature of 650 °C for 12 hours.

As a result of the TG analysis, thermograms were obtained for samples of basalt superfine fiber without binder (Fig. 6). It can be seen that when heated to 650 °C, the mass of the sample decreased by less than 1%. This indicates the thermal stability of this material.

For basalt insulation samples with binder, the thermograms obtained are shown in Figure 7. A 4% change in the mass of samples in the temperature range from 240 °C to 650 °C is associated with thermal degradation of the binder. The beginning of the decomposition process is at temperatures of 238-244 °C.

The effect of high temperature of the insulated surface on the insulating material leads to degradation of the binder used to bond the fibers.

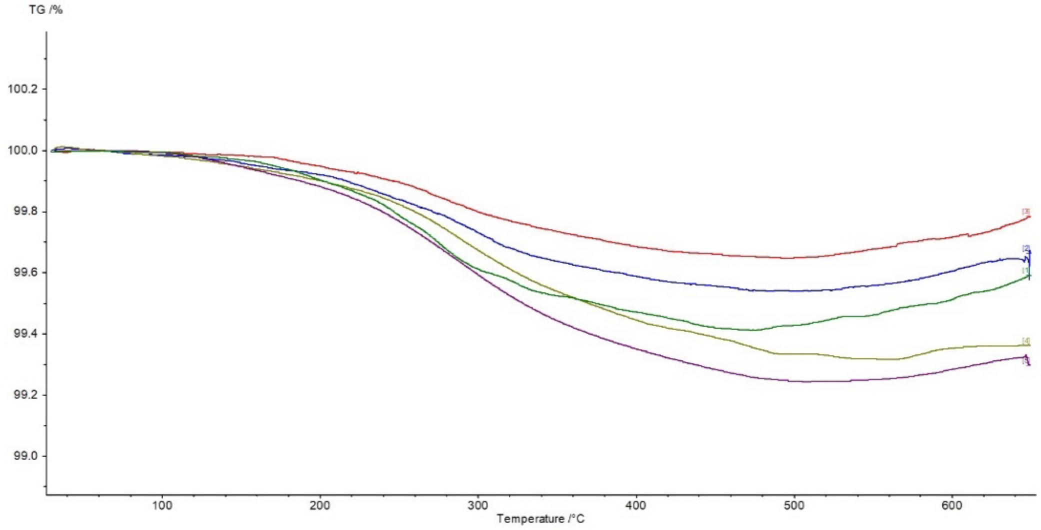

Figure 6: Thermograms for samples of basalt insulation made of supertong fiber without binder.

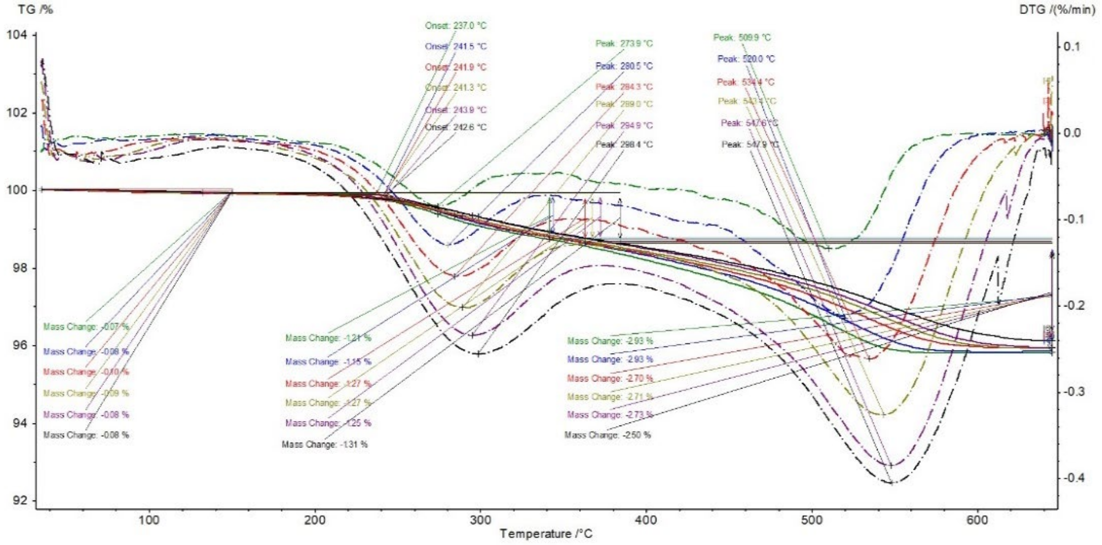

Figure 7: Thermograms for basalt insulation samples with binder.

Figure 8: The appearance of samples of basalt thermal insulation cylinders after 8 hours of operation on a metal pipe with a temperature of 400 ° C.

Figure 8 shows the change in the structure of the basalt thermal insulation cylinder material that occurred with the material during the insulation of a metal pipe with a temperature of 400 °C over 8 hours of operation.

For the samples shown in Figure 8, changes in water absorption were studied. The water absorption of the new samples was 18-23% by weight. The water absorption of samples after thermal degradation of the material structure is 331-413% by weight.

4 CONCLUSIONS

The work investigated the stability of the thermal insulation properties of thermal insulation materials made of basalt fiber with a polymer binder after heat treatment. For all samples, after the binder burns out, the material loosens. It is shown that the use of basalt thermal insulation with a polymer binder on surfaces with temperatures above 250 °C leads to an increase in the coefficient of thermal conductivity during operation by 20% due to thermal degradation of the binder. For objects with an insulated surface temperature above 250 °C, materials without a polymer binder are preferred, which will ensure the stability of thermal protection properties.

The water absorption of basalt thermal insulation during thermal degradation of the binder can increase significantly, which, if the thermal insulation material is moistened during operation, will lead to an even greater increase in heat losses.

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