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# STUDYING THE THERMAL CONDUCTIVITY OF MATERIALS

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**Abstract:** The article is devoted to the determination of the coefficient of thermal conductivity of materials by the method of continuous heat flow. Two types of materials were tested in the experiment: textolite and fluoroplast, which are both heat-insulating and antifriction. The experiment was conducted at the department of "Fundamentals of mechanics and engineering graphics" of the Tashkent institute of chemical technology on a standard laboratory stand. The results of the experiment are presented in the form of summary tables and a graph.

**Keywords:**thermal conductivity, coefficient of thermal conductivity, heat flow, temperature gradient**.**

## 1. Introduction.

The thermal conductivity of materials in the construction of modern structures is essential and important, since comfort and warmth in the living room will depend on which materials were chosen as construction materials. Currently, basalt fiber slabs produced in Uzbekistan, among others, are beginning to be used everywhere in Tashkent during the construction and reconstruction of residential premises [1–9].

In this regard, we consider it necessary and expedient to conduct a comprehensive study to determine their thermal conductivity in laboratory or production conditions before manufacturing and installing such building insulation materials.

## 2. Methods of research.

To conduct experiments to determine the thermal conductivity coefficient of various materials, the department of "Fundamentals of mechanics and engineering graphics" has a corresponding experimental installation. On this type of equipment, studies can be carried out to determine the temperature gradient of various solid materials of round shape and limited thickness. This experimental equipment in the fields of science: thermal engineering and hydraulics, is manufactured by "Zarnitsa" in the Russian Federation (Kazan). Similar laboratory equipment in this area is manufactured in Germany (Hamburg) by GUNT[10–14].

This article provides a methodology for conducting a study on the thermal conductivity of samples made of textolite and fluoroplast. These materials are widely used both in general mechanical engineering and in the construction of various structures.

Recall that the thermal conductivity of materials is the ability of a material body to transfer heat from its more heated parts to less heated ones through the chaotic movement of particles. Consider a layer of a solid substance with a temperature of $T_0$ enclosed between two parallel plates located at a distance of $\Delta h$ from each other. Let the temperature of the lower

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plate rise instantly from $T_0$ to $T_1$ at time τ=0, which does not change at subsequent times. As a result, the temperature profile inside the layer begins to change over time and, at sufficiently high temperatures, a stationary linear temperature distribution is established. In stationary conditions, to maintain the temperature difference (temperature gradient) $\Delta T=T_1-T_0$, a constant heat flow Q is required. For sufficiently small values of ΔT, the ratio is valid:

$$\frac{Q}{F} = \lambda \cdot \frac{\Delta T}{\Delta h} \quad (1)$$

According to expression (1), the rate of heat transfer through a unit surface area of the layer F is proportional to the temperature difference at a distance of Δh. The coefficient of proportionality is called the coefficient of thermal conductivity of the material[15–18].

Equation (1) is also valid in cases where the space between the plates is filled not only with a solid, but also with a liquid or gas, provided that there is no convection and radiation. Thus, this ratio describes the process of thermal conductivity in solids, liquids and gases.

If the local rate of heat transfer through a unit of the layer surface (heat flux density) in the positive direction of the "y" axis is denoted by $q_y$, then at $\Delta h \Rightarrow 0$ the ratio (1) takes the form:

$$q_y = -\lambda \cdot \frac{dT}{dy} \quad (2)$$

This equation is a one-dimensional formulation of Fourier's law of thermal conductivity. It is valid if the temperature depends on only one "y" coordinate. Thus, the following formulation can be given to the law of thermal conductivity: the density of the heat flux due to thermal conductivity is proportional to the temperature gradient. The minus sign in equation (2) means that heat is spreading in the direction of decreasing temperature.

When experimentally determining the coefficient of thermal conductivity, as a rule, they strive to create a one-dimensional temperature field. So, in relation to the one-dimensional temperature field of flat, cylindrical and spherical layers under boundary conditions of the first kind, the equation for determining the thermal conductivity coefficient looks like this:

$$\lambda = \frac{K \cdot Q}{t_1 - t_2} \quad (3)$$

where: Q is the heat flux (in W); $t_1$ & $t_2$ are the temperatures of the outer and inner surface of the layer (ºC); K is a coefficient depending on the shape and size of the test sample ($m^{-1}$) [19–23].

It follows from formula (3) that in order to determine the thermal conductivity coefficient of the material under study, it is necessary to measure in stationary mode the heat flux Q passing through the sample under study and the temperatures of its isothermal surfaces. Formula (3) describes the temperature distribution in solids, as well as in liquids and gases in the absence of heat transfer methods other than thermal conductivity. In the case of a temperature dependence of the thermal conductivity coefficient, formula (3) can be used provided that a small temperature difference occurs in the sample under study.

Despite its methodological simplicity, the practical application of stationary thermal conductivity methods to determine the appropriate coefficients is associated with difficulties in

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creating a one-dimensional temperature field in the studied samples and taking into account heat losses.

In addition, stationary methods require considerable time for conducting experiments due to the duration of the installation's transition to a stationary thermal regime.

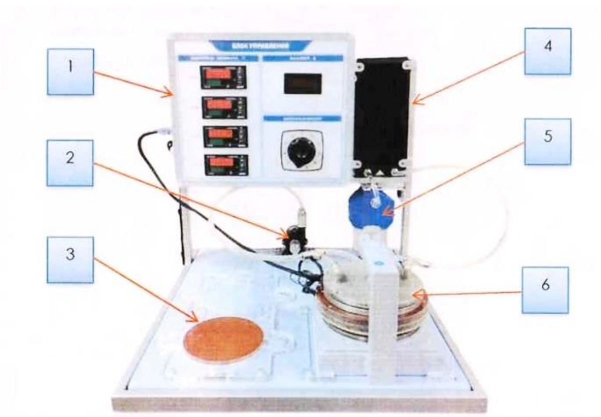
In the study of thermal insulation materials with low thermal conductivity ($\lambda \leq 2,3$ W/m·K), the method of an unlimited flat layer has become widespread, when a sample of the material under study is given the shape of a thin plate. To create a temperature difference, one surface of the plate is heated, and the other is cooled using devices between which the test sample is clamped.

When choosing the geometric dimensions of the studied samples of materials with low thermal conductivity, it is necessary to fulfill the condition: $\delta \leq \left(\frac{1}{7} \dots \frac{1}{10}\right) \cdot D$ (where D is the diameter of a round plate or the side of a square), which ensures the one–dimensionality of the temperature field. Thermal insulation is used to eliminate heat losses from the side surfaces of the sample.

The disadvantages of the method include the difficulties associated with the elimination of thermal resistances that occur at the points of contact of the sample with the surfaces of the heater and refrigerator. The error in determining the thermal conductivity coefficient due to the contact resistance can reach 10-20% with a sample thickness of 1,5-3,0 mm and becomes even greater with an increase in the thermal conductivity of the material under study. To reduce the contact thermal resistance of the surface of the sample and heat exchangers, they are subjected to careful processing, and significant compressive forces are created to ensure good contact.

The experimental stand "Study of thermal conductivity of materials" is made in the form of a desktop stand equipped with a horizontal work surface for the arrangement of the studied laboratory modules and a vertical work surface on which the control and control unit is located (Fig.1). The measuring system of the experimental installation has the ability to output the temperature regime to a personal computer in the form of graphs.

The main module consists of two laboratory samples "4", which are placed between the heater "1" and two refrigerators "2" (Fig.2). The necessary density of contact of the studied samples with hot and cold surfaces is provided by the use of the device "5". To reduce heat losses, the heater has a casing "3".



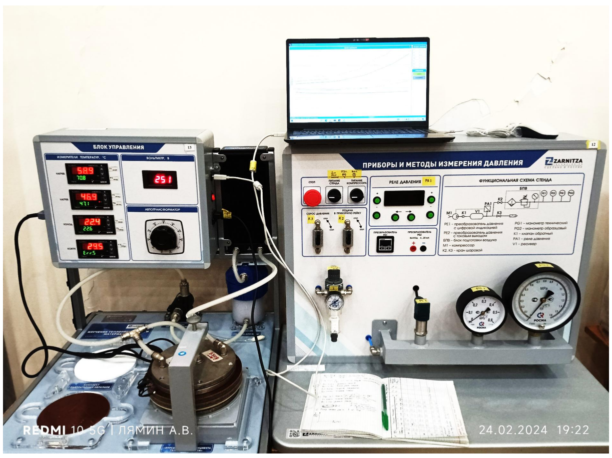



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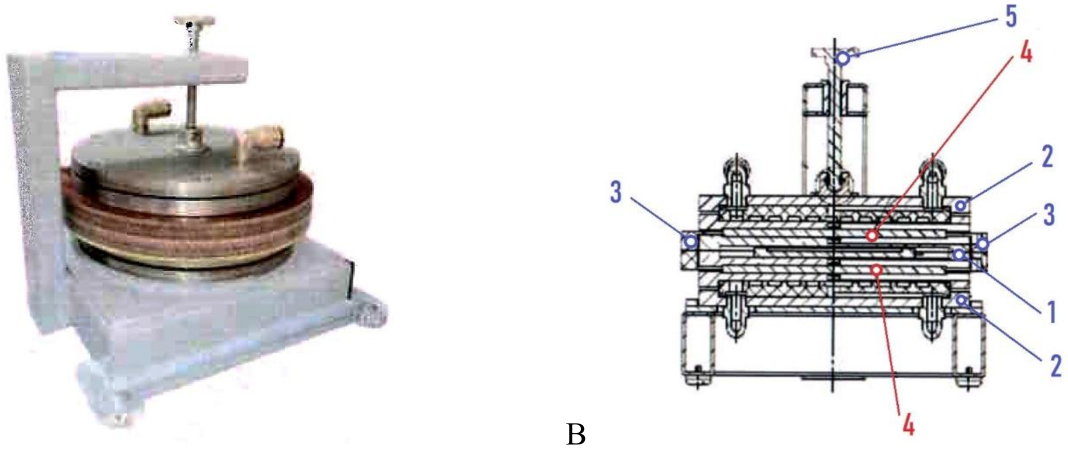
Figure 1. General view of the experimental installation:
1 – control and display module; 2 – centrifugal pump; 3 – set of laboratory samples; 4 – air-water heat exchanger; 5 – water tank; 6 – module "determination of thermal conductivity coefficient".




A B

Figure 2. Image of the main module (position #6, Fig.1):
A – exterior view; B – sectional view; 1 – heater; 2 – refrigerator; 3 – thermal insulation casing; 4 – test sample; 5 – clamping screw.

The main module consists of two refrigerators and one heater (see Fig.2-B). Refrigerators are placed at the bottom and top, and the heater is in the middle of the prefabricated structure. A sample of the test material (specially treated disc) is placed between each refrigerator and the corresponding side of the heater. For a tight fit of the samples to the walls of the refrigerator and heater, the module is equipped with a screw clamp. For temperature measurement, the module is equipped with 7-point temperature sensors with Pt100 calibration.

The stages of the experiment can be represented as the following algorithm:

1. Determination of the average temperature values of the inner hot $t_{ht}$ and outer cold $t_{cd}$ surface of the samples according to the formulas:

$$t_{ht} = \frac{t_1 + t_2 + t_3 + t_4}{4}$$ – the average surface temperature of the samples from the heater side;

$$t_{cd} = \frac{t_5 + t_6}{2}$$ – the average surface temperature of the samples from the refrigerator side.

$$t_{av} = \frac{t_{ht} + t_{cd}}{2}$$ – the average temperature between the hot and cold side of the test sample.

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2. Determination of the heat flux Q passing through the samples: $Q=Q_{ht}-Q_{hf}$, where $Q_{ht}=U^2/R$ is the heat flux from the heater; $Q_{hf}=\frac{5\pi\lambda_{cs}}{2}\left(\frac{d_{ht}+d_{cs}}{d_{cs}-d_{ht}}\right)(\delta_{ht}+\delta_{cs})(t_{ht}-t_{cs})$ - heat losses on the casing.

3. Determination of the coefficient of thermal conductivity according to the formula: $\lambda=\frac{K\cdot Q}{t_{ht}-t_{cd}}=\frac{Q\cdot\delta}{2F\cdot(t_{ht}-t_{cd})}$, where: $K=\frac{\delta}{2F}$ – a coefficient that takes into account the shape of the sample; $\delta$ - sample thickness; $F=\frac{\pi d^2}{4}$ – the surface area of the sample. The installation parameters required for calculations are shown in Table 1.

4. After determining the value of "λ" for two different materials, it is necessary to plot the dependence of the thermal conductivity coefficient on the average temperature.

5. Comparison of the found thermal conductivity coefficients with the corresponding theoretical values. The values of "λ" for some materials are shown in Table 2.

Table 1.
Individual parameters of the experimental mounting.

| Name of the parameter | Numerical value |
|---|---|
| Heater resistance, R | 280 Om |
| Diameter of the heater, $d_{ht}$ | 0,17 m |
| Heater thickness, $\delta_{ht}$ | 0,02 m |
| Sample diameter, d | 0,14 m |
| Sample thickness, $\delta$ | 0,005 m |
| Thermal conductivity coefficient of the casing (material is glass-textolite), $\lambda_{cs}$ | 0,3 W/(m·K) |
| Outer diameter of the casing, $d_{cs}$ | 0,19 m |
| Thickness of the casing, $\delta_{cs}$ | 0,024 m |

Table 2.
The actual thermal conductivity coefficients of some materials.

| Material | $\lambda_0$, W/(m·K) |
|---|---|
| Asbestos ($\rho$=500 kg/m$^3$) | 0,107 |
| Asbestos cement | 0,088 |
| Wool felt | 0,047 |
| Textolite | from 0,23 to 0,34 |
| Fluoroplast | 0,255 |

## 3. The results of the experiment.

The main results of the experiment are presented in tabular form (see Tab.3 and Tab.4) and the dependency graph (Fig.3).

Table 3.
The results of measuring the thermocouple readings at the experimental mounting.

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| № | U, V the voltage on the heater | Thermocouple readings, °C | | | | | | | $t_{ht}$, °C | $t_{cd}$, °C | $t_{av}$, °C | Type of material |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 heating | T2 heating | T3 heating | T4 heating | T5 cooling | T6 cooling | T7 casing | | | | |
| 0 | the room temperature | 18,2 | 18,1 | 18,0 | 18,0 | 17,8 | 18,7 | 20,3 | 18,0 | 18,2 | 18,1 | Fluoroplast |
| 1 | 100 | 26,0 | 28,2 | 23,4 | 23,4 | 26,1 | 26,3 | 23,4 | 25,2 | 26,2 | 25,7 | |
| 2 | 150 | 36,4 | 39,5 | 31,0 | 31,0 | 25,8 | 25,9 | 25,4 | 34,4 | 25,8 | 30,1 | |
| 3 | 200 | 51,2 | 59,7 | 42,2 | 42,3 | 25,1 | 25,1 | 29,7 | 48,8 | 25,1 | 36,9 | |
| 4 | 250 | 71,6 | 84,4 | 58,4 | 58,7 | 25,0 | 25,0 | 36,6 | 68,2 | 25 | 46,6 | |
| 0 | the room temperature | 28,1 | 28,0 | 28,4 | 28,5 | 25,6 | 26,4 | 25,0 | 28,2 | 26 | 27,1 | Textolite |
| 5 | 100 | 31,0 | 33,0 | 29,1 | 29,1 | 21,9 | 21,9 | 24,2 | 30,5 | 21,9 | 26,2 | |
| 6 | 150 | 36,7 | 41,3 | 32,2 | 32,3 | 21,7 | 21,8 | 24,7 | 35,6 | 21,75 | 28,6 | |
| 7 | 200 | 46,0 | 54,0 | 38,2 | 38,3 | 21,9 | 22,0 | 26,5 | 44,12 | 21,9 | 33,0 | |
| 8 | 250 | 61,2 | 73,3 | 49,6 | 49,9 | 22,5 | 22,7 | 30,6 | 58,5 | 22,6 | 40,55 | |

Table 4.
Heat flow measurement results.

| № | U, V the voltage | $Q_{ht}$, W heating | $Q_{hf}$, W losses | Q, W the total | $t_{ht}$, | $t_{cs}$, | $t_{ht}$ - $t_{cs}$ | λ, W/(m·K) | Type of material |
|---|---|---|---|---|---|---|---|---|---|

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| | on the heater | | | heat flow | °C | °C T7 | °C | the coefficient of thermal conductivity | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | the room temperature | | | | 18,075 | 20,3 | | | Fluoroplast |
| 1 | 100 | 35,71429 | 3,450546 | 32,26374 | 25,25 | 23,4 | 1,85 | -5,739033 | |
| 2 | 150 | 80,35714 | 16,92633 | 63,43082 | 34,475 | 25,4 | 9,075 | 1,2427645 | |
| 3 | 200 | 142,8571 | 35,71781 | 107,1393 | 48,85 | 29,7 | 19,15 | 0,7623121 | |
| 4 | 250 | 223,2143 | 59,07894 | 164,1353 | 68,275 | 36,6 | 31,675 | 0,6409329 | |
| 0 | the room temperature | | | | 28,25 | 25,0 | | | Textolite |
| 5 | 100 | 35,71429 | 11,84377 | 23,87052 | 30,55 | 24,2 | 6,35 | 0,4516231 | |
| 6 | 150 | 80,35714 | 20,37687 | 59,98027 | 35,625 | 24,7 | 10,925 | 0,7074663 | |
| 7 | 200 | 142,8571 | 32,87345 | 109,9837 | 44,125 | 26,5 | 17,625 | 0,8116991 | |
| 8 | 250 | 223,2143 | 52,03796 | 171,1763 | 58,5 | 30,6 | 27,9 | 0,7803322 | |

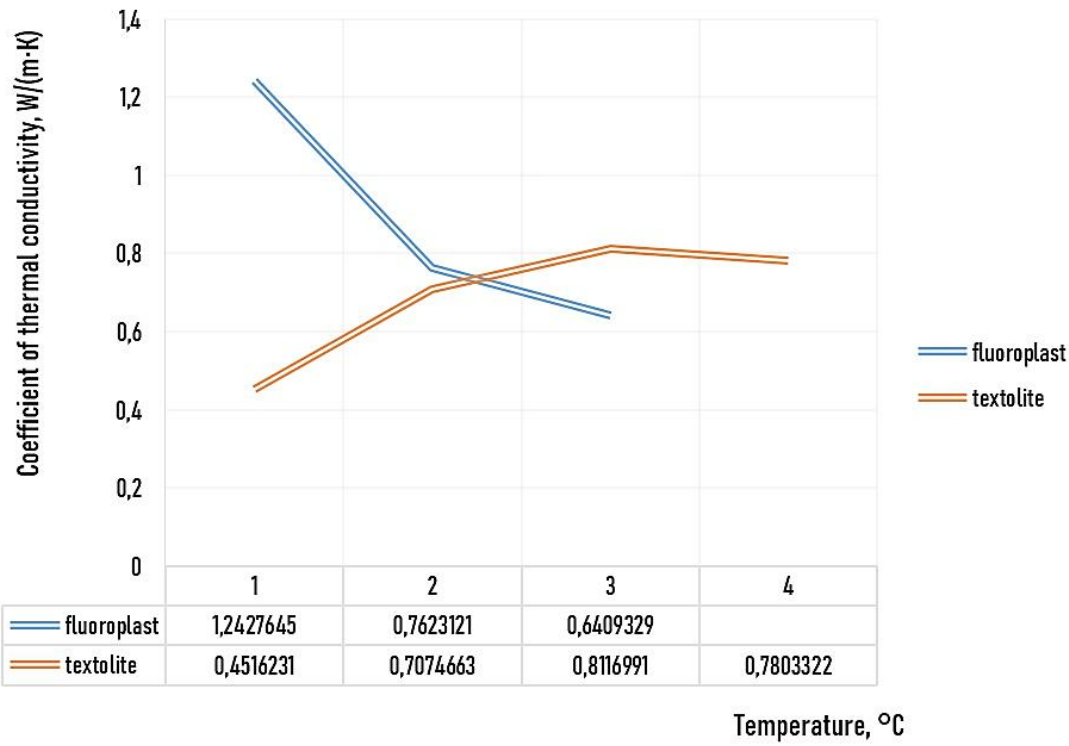

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Figure 3. Graph of the dependence of the thermal conductivity coefficient on the average temperature.

## 4. Discussion of the results.

According to the results of the conducted studies, it can be seen that the theoretical values of the thermal conductivity coefficients of textolite and fluoroplast differ greatly from each other. So, according to Table 2, for textolite this value ranges from 0,23 to 0,34 W/(m·K), which is 2,3 times less than the obtained average experimental values; for fluoroplast, the reference values range from 0,255 W/(m·K), which is as much as 3,5 times less than the obtained average experimental values. Thus, it makes sense to re-conduct studies for different temperature and time ranges..

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