The empirical evaluation of thermal conduction coefficient of some liquid composite heat insulating materials

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Abstract. We experimentally determined the coefficients of thermal conductivity of some ultra thin liquid composite heat insulating coatings, for sample #1 λ = 0.086 W/(m·°C), for sample #2 λ = 0.091 W/(m·°C). We performed the measurement error calculation. The actual thermal conduction coefficient of the studied samples was higher than the declared one. The manufactures of liquid coatings might have used some "ideal" conditions when defining heat conductivity in the laboratory or the coefficient was obtained by means of theoretical solution of heat conduction problem in liquid composite insulating media. However, liquid insulating coatings are of great interest to builders, because they allow to warm objects of complex geometric shapes (valve chambers, complex assemblies, etc.), which makes them virtually irreplaceable. The proper accounting of heating qualities of paints will allow to avoid heat loss increase above the specified limits in insulated pipes with heat transfer materials or building structures, as well as protect them from possible thawing in the period of subzero weather.

1. Introduction

At present, the construction market has a wide range of different heat-insulating materials. Recently, some firms began to offer advanced ultra-thin insulating liquid composite coatings (hereinafter insulating paints) which thermal conductivity is λ = 0.001 ÷ 0.0015 W/(m·°C) for heat insulation of house fronts, and utilities. As a comparative example, they often provide the data that a layer of such paint with the thickness of 1 to 3 mm coated on engineering pipes can successfully replace the insulation of widely known mineral wool heat insulators with the thickness of a few centimeters [1, 2].

In the sphere of housing and communal services the application of heat insulating materials can result in substantial energy savings [3]. However, the heat transfer properties of the submitted data of heat-insulating coatings are not fully studied. The existing studies of various authors [4-7] on determination of thermal conductivity of the same type of heat-insulating paints often demonstrate a significant difference.

In this connection, it was decided to conduct the experimental determination of the thermal conductivity of some samples of insulating paints (as one of the main thermal characteristics of these coatings) in order to reveal their true value.

2. The existing methods of determination materials thermal conductivity

To review the methods of determination of materials thermal conductivity we should noted the work of such authors as Y.Y. Golovach (FSUE RI «Santechniki»), A.V. Shvetsov (Capstone Manufacturing), Y.F. Kolkhir (JSC «Predpriyatie Itil»)) [5]. The present method determines the thermal conductivity of insulation under strictly defined environmental conditions, which is not always possible to achieve. There are also several legal methods of determination of thermal conduction coefficient of various building materials [8, 9]. The relative error in determining the effective thermal conductivity and thermal resistance by method [9] does not exceed ± 3% if the test is carried out in full compliance with the requirements of the standard.

There is a method for determining the thermal conductivity using the "support wall" (the layer may be used as heat insulation) [10] consisting of two layers of material, one of which is with a known thermal conduction coefficient, placed on a heat source.

There is also a modern patented method for determination of the thermal conduction coefficient of ultra thin liquid heat insulating coatings [11].

The analysis of the usability conditions of the existing methods showed that the standard method [8] is designed to measure mainly the heat-conduction coefficient of bulk materials that does not meet the initial requirements. The method [5] is highly demanding to the accuracy of maintaining the temperature conditions. The method [11] is developed for section $\lambda = 0.01 \div 0.009$ W/ (m·°C).

Besides the works of Russian scientists in the sphere of the thermal conduction coefficient determination of insulating paints the similar experiences of foreign experts in the solution of similar problems has been analyzed [12-17].

In accordance with the performed analysis of the existing methods it was decided to use some samples of insulating paints of standard method [9] with the replacement of a heat meter with the layer of material with a known conductivity for the experimental determination of the thermal conduction coefficient. Such change is correct and does not contradict the theory of the study of thermal processes [10]. The method [9] meets all the requirements for conducting the experiment (the standard is not applied to materials and products with a thermal conductivity of more than 1.5 W/(m ·°C) and the relative error in determining the effective thermal conductivity and thermal resistance according to the method [9] does not exceed ± 3%).

3. Description of the experiment

For the experiment, the authors have reviewed the list of the most well-known manufacturers of liquid heat insulating coatings (mascoat, tsmceramic, thermalcoat, Isollat, Astratek, Alfatek, Teplokott, Corund etc.).

Two samples of the above brands of liquid heaters were selected for the study, which were named "Sample" (here in after Sample #1 and Sample #2). Several sample characteristics are given in the Table. 1.

Table 1. Some the stated characteristics of experimental samples.

Characteristic's name	Unit of measurement	Sample #1	Sample #2
Colour of coating		white	white
Heat conductivity	W/(m·°C)	0.0011	0.002 – 0.007
Density	kg/m^3	390	280
Vapor transmission	mg/(m·h·Pa)	0.012	0.012
Water permeability	kg/(h·m·0.1GA)	less than 30	less than 30

The manufacturers of heat insulating paints often do not provide full information on the physico-chemical composition of the heat insulating coatings produced by them, so the information on the composition of the heat insulating paints of the studied samples was obtained from official sites of the

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manufacturers. The paints include: glass ceramic microspheres, binders, dispersants, fillers, pigments, thinners. Typically, the suppliers do not provide the percentage of ingredients.

The measuring complex was developed for the experiment, it includes: The apparatus for testing samples (figure 1); the appliance "Terem-4.0" for measurement of thermocouples readings; "Chromel-Copel" thermocouples are made of wire with the thickness of $\delta = 0.2$ mm; the plate of a material with a known heat conductivity (plexiglas, with the thickness $\delta = 3.2$ mm, $\lambda = 0.19$ W/(m·°C), which is a replacement for heat meters.

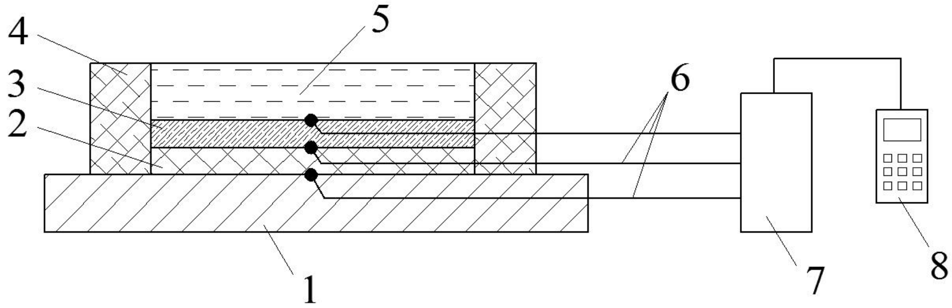

Figure 1. Schematic diagram of measuring complex:
1 - source of continuous heat flux; 2 - the layer of the material with known thickness and heat-conducting coefficient (plexiglas); 3 - the layer of heat insulating paint; 4 - insulator (polystyrene); 5 - "refrigerator" (a container with water); 6 - thermocouple between the layers; 7 - Switch; 8 - measuring device "Terem 4.0"

Paint in the layer 3 (figure 1) was applied evenly onto a copper plate of 0.5 mm thickness. The heat flux density q_i, W/m^2 depending on (1) is determined by calculation:

$$q_u = \frac{\lambda_{\text{layer}\,2}(t_1 - t_2)}{\delta_{\text{layer}\,2}}, \qquad (1)$$

where $\lambda_{\text{layer 2}}$, $\delta_{\text{layer 2}}$ is a thermal conducting coefficient and the thickness of plexiglas layer (figure 1), t_1, t_2 are temperatures on the borders «the source of heat is a layer of plexiglas» and «the layer of plexiglas is a tested sample» accordingly (figure 1).

The thermal conductivity of copper plate with the thickness $\delta = 0.5$ mm, equals $\lambda = 384$ W/(m·°C). The temperature and relative air humidity indoors during the experiment were equal to $t_в = 24$ °C, and $\varphi = 40\%$.

To stabilize the readings of the appliance during its "warming" and heat flux transfer into a stationary mode the control measurements of appliance reading dynamics were performed according to 3 sensors of thermocouples within 0.5 hours in increments of of 5 minutes measurement. At steady state the readings came to stationary mode in 20 minutes after the start of its operation. For defining the individual error of thermocouple sensors the temperatures measurement for each sensor immersed in a "Dewar" vessel filled with snow slush were performed before the experiments. The obtained temperature deviations from 0 °C temperature were also noted during the experiments.

The calibration was performed to test the adequacy of the developed appliance, measurement of thermal conduction of insulating paints. The plexiglas plate similar in size, thickness and the thermal conductivity to the plate in layer 2 was placed instead of layer 3 (figure 1) into the appliance. The calibration measurements were conducted. Due to the measurement results it was found that thermal conductivity of tested plexiglas plate was $\lambda = 0.186$ W/(m·°C). The error of the method of measuring the thermal conductivity was 2.1%.

The findings suggest that the error of this method does not exceed the error stated in the State Standard [12] (± 3%), which indicates the correctness of the chosen research scheme.

4. The analysis of the experiment results

Sample #1 and Sample #2 were tested at various temperature modes in different heat fluxes in purpose to analyze the dynamics of changes of thermal conduction coefficient depending on temperature of paint samples. The obtained results are presented in figure 2 and figure 3 correspondingly.

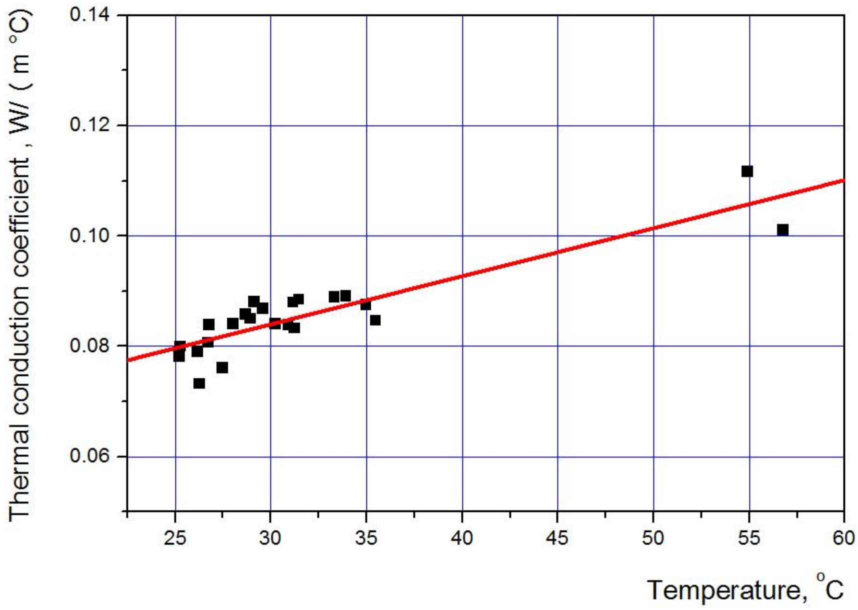

Figure 2. The results of the experiment on defining the paint thermal conductivity (sample #1)

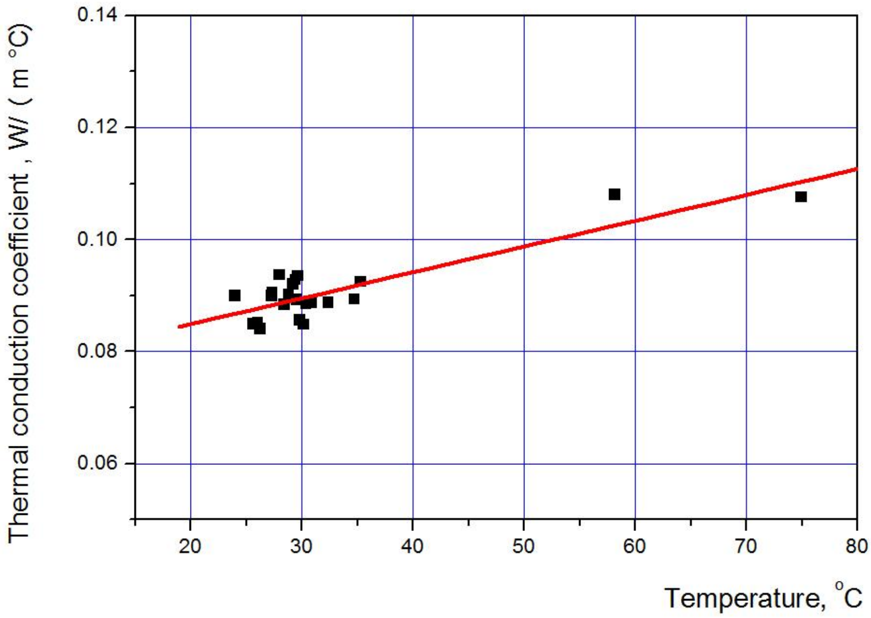

Figure 3. The results of the experiment on defining the paint thermal conductivity (sample #2)

The measurement error calculations was conducted by dependences (2-4)

$$\bar{A} = \frac{\sum_{i=1}^{n} A_i}{n}, \quad (2)$$

where A is a measured value, $\bar{A}$ is a medium value of the calculated value, $\Delta\bar{A}$ is an absolute error of medium value of the calculated value defined by the formula

$$\Delta\bar{\bar{A}} = t_{y,n-1} \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(A_i - \bar{\bar{A}}\right)^2}{n-1}}}{\sqrt{n}}, \quad (3)$$

where $t_{y,\,n\text{-}1}$ is Student's coefficient (by $t_{95\%,\,23}$= 2.074).

The relative error of medium value of the measured value is calculated by dependences [17]

$$\varepsilon = \frac{\Delta\bar{A}}{\bar{A}}. \quad (4)$$

The measurement error made ε = 1.85%. The total error in the determination of thermal conductivity taking into account the error of the study method (3%), and the appliance error (1%) was 5.85%.

5. Conclusion

As a result of this work the thermal conducting coefficient of ultrathin liquid composite thermal insulating coatings has been experimentally determined. For «Sample #1» it makes λ = 0.086 W/(m·°C), for «Sample #2» it makes λ = 0.091 W/(m·°C).

Undoubtedly, the given liquid coatings can be attributed to the heat insulating materials. According to their thermal conducting characteristics they are equal, for example, to mineral wool (λ = 0.07 W/(m·°C) or foam glass (λ = 0.1 W/(m·°C). However, their real thermal conducting coefficient is higher than declared. The given difference is possible due to the fact that the manufacturers of liquid coatings used some "ideal" conditions, or the coefficient was obtained by the theoretical solution of the problem of thermal conduction in liquid composite insulating media at laboratory determining of the thermal conductivity

Despite this, these liquid insulating coatings are of great interest to builders, because they allow to warm objects of complex geometric shapes (valve chambers, complex assemblies, etc.), which in some cases makes them virtually irreplaceable.

The proper accounting of the thermal conducting characteristics of paints will prevent excess increase of heat losses in insulated pipes with thermal transfer materials or building structures, as well as protect them from possible thawing in the period of subzero weather.

This study does not claim to be the "definitive" and is probably aimed at the prerequisites for further study of thermal insulating properties of modern composite liquid thermal insulating coatings, because their thermal properties are not adequately studied to date.

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