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Effects of moisture content on thermal conductivity of thermal insulation materials

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Abstract. Insulation materials play an important role in district heating pipeline networks. Thermal losses in pipe insulation systems depend on the thermal conductivity of insulation materials. The thermal conductivity of the insulation materials is influenced by the temperature and moisture content. In this paper the effect of moisture content on the thermal conductivity of rock wool produced by different manufacturers was considered. Experimental studies were performed using the standard guarded hot plate (GHP) method. Higher thermal conductivity is always associated with higher moisture content for all investigated samples.

1. Introduction

Growing population and increasing consumption of energy resources increase the importance of energy saving and rational use of energy [1]. One of the potential sectors that reduce energy consumption is heating networks [2]. The first district heating system appeared in New York in 1877. Since then, they began to spread to many European countries [3]. Heat losses in pipeline networks are dependent on insulating materials. [4,5]. The potential for energy saving is available in the building sector. Energy saving in the building sector also depends on insulation materials [6]. The main characteristics of insulating materials is thermal conductivity. Thermal conductivity depends on temperature and moisture content [7,8]. In paper [8], the effect of moisture content on the thermal conductivity of fibrous insulation materials at different insulation temperatures was investigated. The study was conducted for fiberglass, mineral wool and rock wool at different densities. Insulation temperature values ranged from 14 to 34 °C, moisture content from 0 to 46.6%. Higher thermal conductivity for the investigated densities is always associated with higher moisture content. The maximum increase in thermal conductivity is observed for mineral wool. The increase in thermal conductivity can reach 446% with an increase in the moisture content of 15%. The authors [9] showed that when the mineral wool is moistened, the thermal conductivity can increase up to 24 times. The article [10] showed that when fiberglass is moistened up to 1%, there is an increase in heat losses. The article [11] also determined the thermal conductivity of various insulating materials. Moistened was carried out in the climate chamber. A sample of mineral wool adsorbed a very small amount of water about 2%. Unfortunately, small fluctuations of thermal conductivity values (around 3%) do not fall into the accuracy of the experimental method. In another article [12], it was found that the thermal conductivity of fiberglass can increase by 300% with an increase in moisture content by 3%. In the article [13], the effectiveness of insulation of pipes made of fiberglass used in district heating and cooling systems subjected to underground water attack has been investigated. The authors of the article found that the thermal conductivity of insulation can increase from 52 to 185 times depending on the temperature of the surrounding water. The authors of [14] investigated the issue of the operation of piping systems with fibrous insulation under conditions of moisture condensation. It is established that the thermal conductivity of the insulation increases systematically with the penetration of water vapor. The thermal conductivity of wet insulation can increase to 3.51 with a moisture content of 15.1%.

The values of thermal conductivity of insulation materials are usually specified by manufacturers. The values of thermal conductivity are given as a function of temperature. However, when using fibrous insulation materials in heat networks, they may be wetted. Typically, manufacturers do not provide data on the thermal conductivity of insulation materials when they are wetted. Data on the effect of moisture on the thermal conductivity of insulating materials is limited. This is also due to the fact that new manufacturers of insulating materials appear on the market. The purpose of this article is to study the thermal conductivity of modern insulation materials of district heating systems, with different levels of moisture content.

2. Methodology

To achieve the goal of the study, fiber insulation materials had dimensions of 150x150 mm, the thickness of the samples was 40–50 mm (figure 1). For the study, samples from rock wool from three different manufacturers were selected (Table 1.). When measuring the thermal conductivity of insulating materials with moisture content, it is necessary to choose the method of their wetting. For moistening insulation materials, the flooding method, the injection method, the laboratory preconditioning method and the ambient temperature with cold surface are used [15]. This article used the injection method because it is simpler and does not require additional equipment. Moisture was injected uniformly over the entire surface of the samples. Desired amount of moisture content determined by weight.

To measure the thermal conductivity of pipe insulation systems, the standard method is used [16]. Measurements are carried out on a cylindrical heated tube. The temperature on the inner side of the insulation is set by the heated pipe, the outer temperature of the wall insulation is cooled by the laboratory atmosphere. Another standard method is guarded hot plate (GHP) [17]. In this case, measurements are carried out on flat samples. The temperature difference between the faces of the samples is set by the heated plates. One of the plates can also be cooled. This method [17] is simpler because it facilitates sample preparation. It is not necessary to build insulation on a cylindrical tube. In this case, thermal conductivity is measured through flat wall that may give inaccuracy in measurements. However, in article [18] has shown that the thermal conductivities obtained on a flat slab specimen can be used to determine the value of a circular pipe. In this work, the GHP method was used to measure the thermal conductivity of pipe insulation systems.

Figure 1. Samples insulation material.

Table 1. List of test samples ordered by code, densities and thickness.

Material type	Sample code	Density ρ (kgm^{3-1})	Thickness δ (mm)
Rock wool	RW-01	80	40
Rock wool	RW-02	80	40
Rock wool	RW-03	80	40

3. Results and discussion

Measurements of thermal conductivity of insulation materials were carried out for dry samples and at three values of the moisture content of 5%, 9.5%, 13.6%. The average temperature of the samples was 26.7±2.5°C. When installing the insulating material on the pipe insulation systems, it is compacted; therefore, during the tests, the material was pressed to density ρ*. The results of the experiment are presented in table 2 and figure 2–3. The mean deviation of the obtained data is 9.2%. For all samples, an increase in thermal conductivity *k* is observed with increasing moisture content MC. Despite the fact that the samples of the insulation material had the same characteristics (table 1), an increase in the MC content may affect the *k* value in different ways depending on the manufacturer of the insulation material. This feature is more noticeable with MC values > 10%. An increase in moisture content has a greater effect on the RW-1 sample. The thermal conductivity of the RW-1 sample increased by 312.8% with an increase in MC by 13.6%. The effect of MC on the thermal conductivity *k* of samples RW-2 and RW-3 is similar. The differences in the *k* values of the RW-2 and RW-3 samples are in the range of accuracy of the experimental measurement. The thermal conductivity of RW-2 and RW-3 samples increased by 81.3–112.7% with an increase in MC by 13.6%. In article [9], at a temperature of 22°C and a MC of 5–20%, the thermal conductivity of mineral wool was 0.10–0.14 W/m°C. In our studies, the *k* values are in a wider range of 0.047–0.148 W/m°C, while the MC values were in a narrower range of 5–13.6%. In article [8], at a temperature of 24°C and a MC of 5–15%, the thermal conductivity of rock wool was 0.0398–0.0399 W/m°C, which is almost similar to a dry material. This data is not consistent with our data. Perhaps this is due to the fact that the density of the rock wool sample in the article [8] was =46 kg/m^3. However, in the same article [8], at a density of mineral wool of 145 kg/m^3 and for the same values of MC and temperature, the thermal conductivity of mineral wool was 0.0696–0.113 W/m°C, which is closer to our values.

Table 2. Measurement results of *k* of rock wool for different manufacturers with different moisture content levels (MC %) under 26.7±2.5 mean operating temperatures.

Sample code	ρ* (kgm^{3-1})	MC (%)	*k* at 26.7±2.5 (°C)	
			W/m°C	% Change
RW-01	119	0	0.036	
	122	5	0.060	69.0
	120	9.5	0.079	121.5
	120	13.6	0.148	312.8
RW-02	119	0	0.036	
	120	5	0.052	46.0
	118	9.5	0.062	72.7
	121	13.6	0.065	81.3
RW-03	118	0	0.036	
	121	5	0.047	31.5
	120	9.5	0.068	91.0
	120	13.6	0.076	112.7

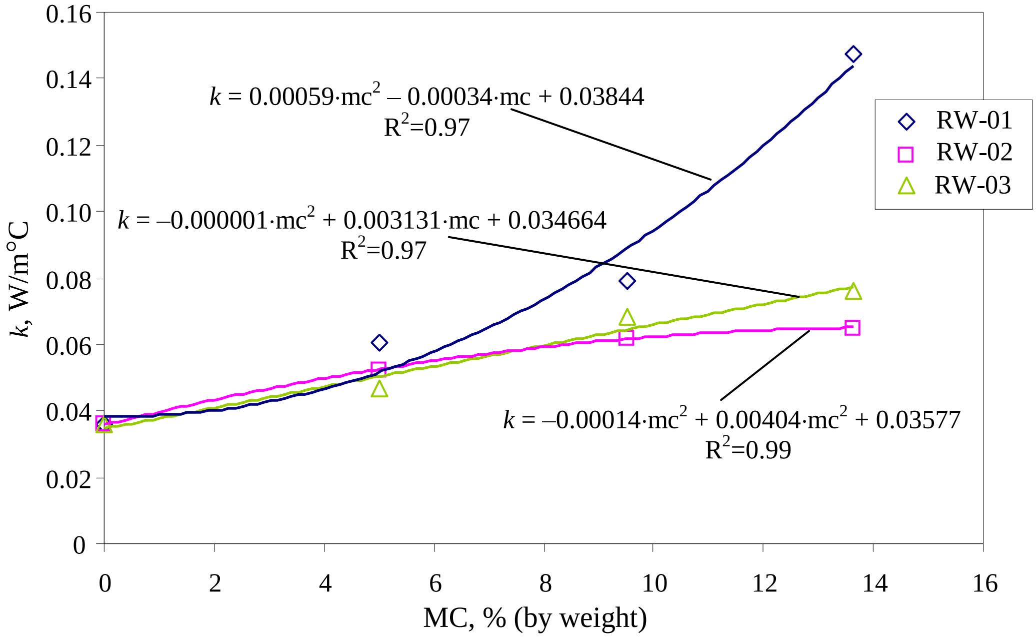

Figure 2. Thermal conductivity of rock wool as a function of moisture content.

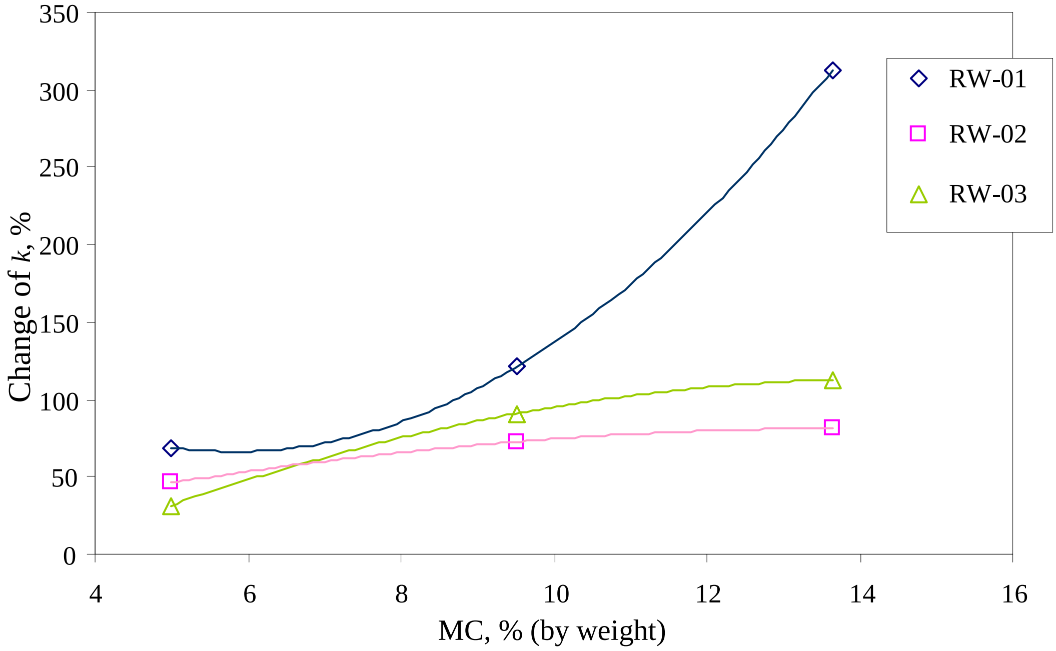

Figure 3. Change of *k* of rock wool, with increase of MC.

4. Conclusion

The thermal conductivity of the insulation material used in district heating networks was investigated. The effect of moisture content on the thermal conductivity of rock wool made by different manufacturers was considered. Higher thermal conductivity is always associated with higher moisture content for all investigated samples. The moisture content of the MC can affect the value of thermal conductivity in different ways depending on the manufacturer of the insulating material. For sample RW-01, thermal conductivity at MC=13.6% increased by 312.8% compared with dry material. For samples RW-02 and RW-03, at MC=13.6%, thermal conductivity increased by 81.3% and 112.7%, respectively.

This study was conducted for one temperature and density of insulating material, that limits the obtained results. As shown in [8], the temperature and density of a material can significantly affect the thermal conductivity. It is also necessary to obtain data on thermal conductivity in a wider range of MC values. Another problem is the possible inaccuracy of determining the thermal conductivity of insulation materials with moisture content using the GHP method [19]. This will be taken into account in our further research.

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