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Thermal Conductivity of Insulation Material: Effect of Moisture Content and Wet-Drying Cycle

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Abstract. The insulation materials are widely used in petrochemical, power engineering and other industries. The thermal insulation materials play an important role in the energy saving of district heating systems and in the building sector. In this work, the thermal conductivity of rock wool with different levels of moisture content and density of the insulation material was investigated by an experimental method. Experimental studies were carried out on rock wool from three different manufacturers. The effect of the wetting and drying cycle on thermal conductivity and density of the insulating material is analyzed. The thermal conductivity of the insulating material was measured using the guarded hot plate method. It was found that the thermal conductivity of insulating materials significantly affected the moisture content. The increase in thermal conductivity was from 1.33 to 4.42 times, depending on the density and the manufacturer of the rock wool. The wetting and drying cycles increase the thermal conductivity and density of the insulating material up to 2 and 2.5 times, respectively.

Introduction

The thermal insulation materials play an important role in the energy saving of district heating systems and the building sector and generally are widely used in many industries such as petrochemical, power engineering, mechanical engineering, etc. District heating in Russia requires about 50% of all energy supplied to buildings [1] and about 44% of the world's all heat production capacity [2], therefore there is a great potential for energy savings. There is also greater potential for energy savings in district heating in heat distribution in Europe [3]. Different insulation materials are used to reduce heat losses in heating networks [4,5]. The efficiency of energy supply in district heating systems and energy consumption in the building sector directly depends on the thermophysical properties of thermal insulation materials. [6-9]. The efficiency of the insulating materials depends on the environmental conditions. The penetration of moisture into the insulating material leads to an increase in heat losses [10–14]. The efficiency of the insulation materials can change by wet-dry, humid-heat, high-low temperature conditions of the environment [15]. Periodic flooding of insulation materials of underground pipelines leads to increases heat losses [16]. Wetting and drying cycles can increase the density of insulation materials and change their thermophysical properties [17].

In work [18], the effect of moisture content on thermal conductivity was studied at a single density value of insulating materials. This article presented results on the effect of moisture content on the thermal conductivity of thermal insulation material with different densities. The effect of wet-drying cycles on the characteristics of insulation material also was studied.

Methodology and Measurement Apparatus

The samples of rock wool (RW-1, RW-2, RW-3) of three different manufacturers were prepared for experimental studies (Figure 1). The dimensions of the samples were 150x150x40 mm. The nominal density of the samples was $\rho = 80$ kg/m^3.

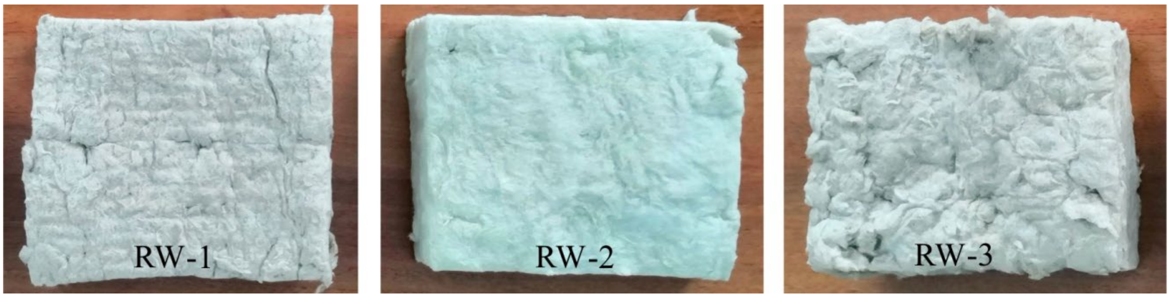

Fig. 1. Samples of rock wool.

The insulation materials studied in this work are commonly used in district heating. Typically, the thermal conductivity of insulating materials of cylindrical pipes is determined by the method [19]. However, the possibility of using the method [20] intended for flat samples instead of [19] was shown in [21]. Therefore, the thermal conductivity of the samples was determined according to the guarded hot plate method [20] on the measurement apparatus ITS-1 (Figure 2.). Description of work of the measurement apparatus ITS-1 is given in [18].

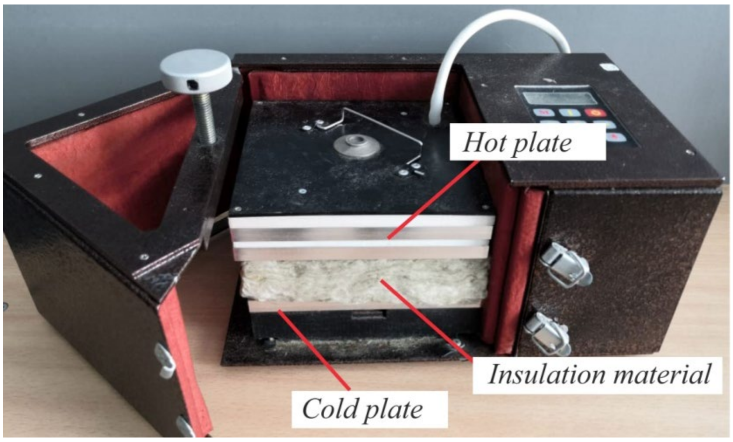

Fig. 2. Measurement apparatus ITS-1.

The average temperature T of the samples during the measurements was maintained equal to 26±4.1 C. The influence of moisture on the thermal conductivity of insulating material was investigated at two artificial densities ρ^* of samples were 100 and 140 kg/m^3. The density ρ^* of insulating materials was established artificially by changing their thickness. For this, the samples were compressed between two plates in an ITS-1 apparatus and remained in this position during measurements. The moisture content MC of the samples was 5, 9.5, and 13.6%. To moisten samples, moisture was injected uniformly over the entire surface of the samples until the required MC by weight was reached. The mean error of the thermal conductivity was about 7.3%. The results obtained were also compared with the results of the previous work [18] at the ρ^* = 120 kg/m^3.

The effect of wet-drying cycles on the properties of the insulation material was carried out with the following steps:

1. Sample of insulation material was immersed in water for 30 minutes;
2. Sample was dried at the temperature of 120 °C in drying chamber;
3. Change of the density ρ_n/ρ of the sample was determined;
4. Change of the thermal conductivity k_n/k of the sample was determined;
5. Steps 1-4 repeated.

Results and Discussion

Results of the experiments show that higher moisture content is always leads to an increase of thermal conductivity of samples for the investigated densities $\rho^* = 100$ and $140\ kg/m^3$ (figure 3,5). The effect of moisture content is most significant for the thermal insulation material RW-1. Results of the measurements agree with the data obtained in the previous article [18] at the density $\rho^* = 120\ kg/m^3$ (figure 4). The samples with higher density generally have large changes in thermal conductivity at the same MC. For example change of thermal conductivity k of the RW-2 sample at the density $\rho^* = 100\ kg/m^3$ is about 61 % at the MC = 9.5 % and it is about 76 % and 84 % for densities of $\rho^* = 120$ and $140\ kg/m^3$ respectively. The change of density ρ^* has a smaller effect on k without the presents of MC. Magnitude of change of k does not exceed 2 % for all samples and investigated densities.

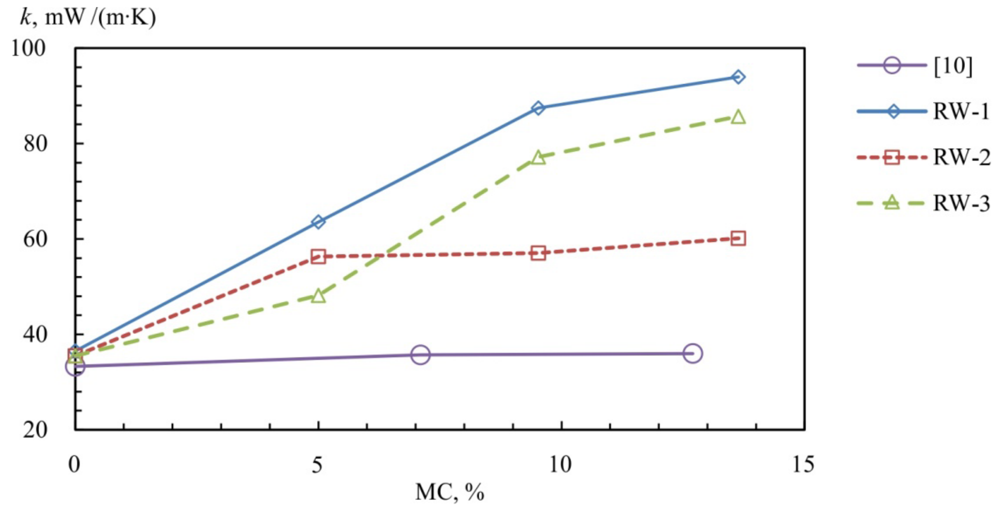

Fig. 3. Variation of thermal conductivity of rock wool with moisture content at the density $\rho^* = 100\ kg/m^3$ and obtained results by Abdou A [10] at the temperature 24 °C and density $\rho = 99$.

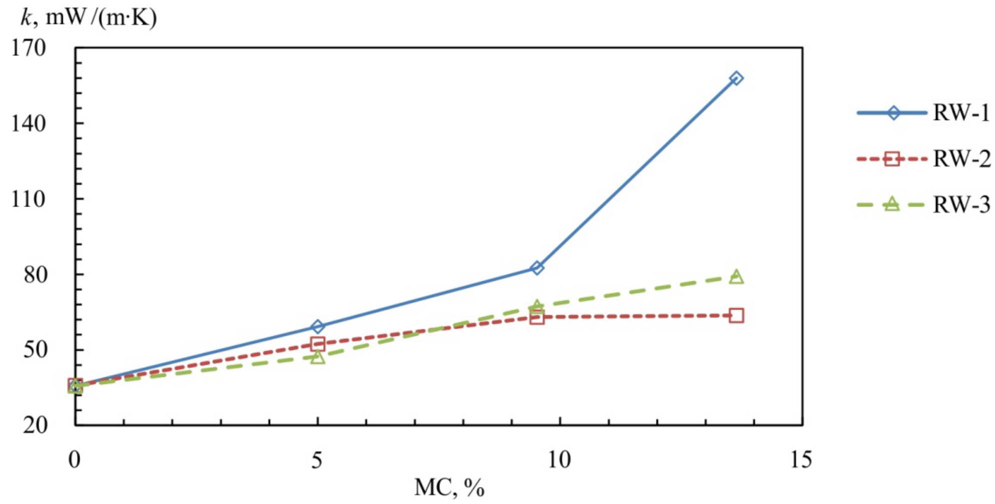

Fig. 4. Variation of thermal conductivity with moisture content at the density $\rho^* = 120\ kg/m^3$ [18].

The results obtained in this work are compared with paper [10] at similar densities and temperatures for rock (Figure 3) and mineral wool (Figure 5). There is a good agreement between the thermal conductivity of dry samples (Figures 3, 5). The effect of moisture on the thermal conductivity of the RW-1 sample at a density of 140 is in good agreement with [10] (Figure 5). However, at a density of 100 in work [10], the effect of moisture content was not significant in comparison with this work (Figure 3).

Based on the results of experimental studies, the empirical equations (1)–(3) were obtained for predicting the magnitude of change of thermal conductivity k_{wet}/k_{dry} of insulating material with the presents of MC.

RW-1 $$\frac{k_{wet}}{k_{dry}} = 10.88 \cdot \left(\frac{\text{MC}}{100}\right)^{0.723} \cdot \left(\frac{\rho^*}{\rho}\right)^{0.793} \quad (1)$$

RW-2 $$\frac{k_{wet}}{k_{dry}} = 2.49 \cdot \left(\frac{\text{MC}}{100}\right)^{0.181} \cdot \left(\frac{\rho^*}{\rho}\right)^{0.088} \quad (2)$$

RW-3 $$\frac{k_{wet}}{k_{dry}} = 6.303 \cdot \left(\frac{\text{MC}}{100}\right)^{0.515} \cdot \left(\frac{\rho^*}{\rho}\right)^{0.169} \quad (3)$$

Here k_{dry}, k_{wet} – thermal conductivity of dry and wet insulation material. ρ, ρ^* – nominal and artificial density of insulation material. The empirical equations (1)–(3) obtained for the ranges of densities $100 \le \rho^* \le 140$ kg/m^3, and MC 5%≤ MC ≤ 13.6%. The maximum difference between equations (1)–(3) with experimental data was about 24.63%, 7.93%, 11.5%, for RW-1, RW-2, RW-3, respectively.

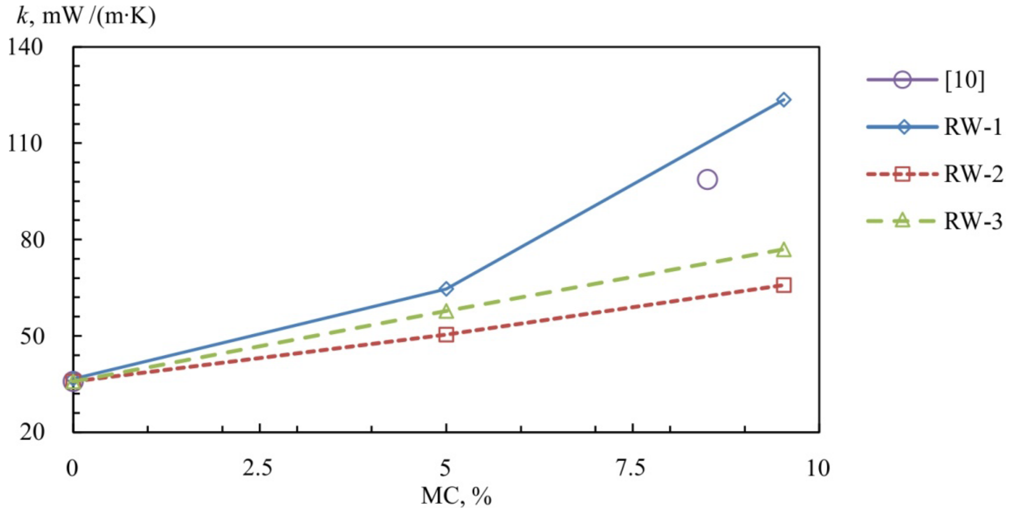

Fig. 5. Variation of thermal conductivity with moisture content at the density $\rho^* = 140$ kg/m^3 and obtained results by Abdou A [10] at the temperature 24 °C and density $\rho = 145$ for mineral wool.

In figures 6,7 shows the effect of wet-drying cycles on thermal conductivity k and density ρ of the samples. The wet-drying cycles increase the thermal conductivity k and density ρ of samples. The impact of wet-drying cycles on the thermal conductivity is more significant for the RW-1 sample. The effect on density ρ is more significant for the RW-2 sample.

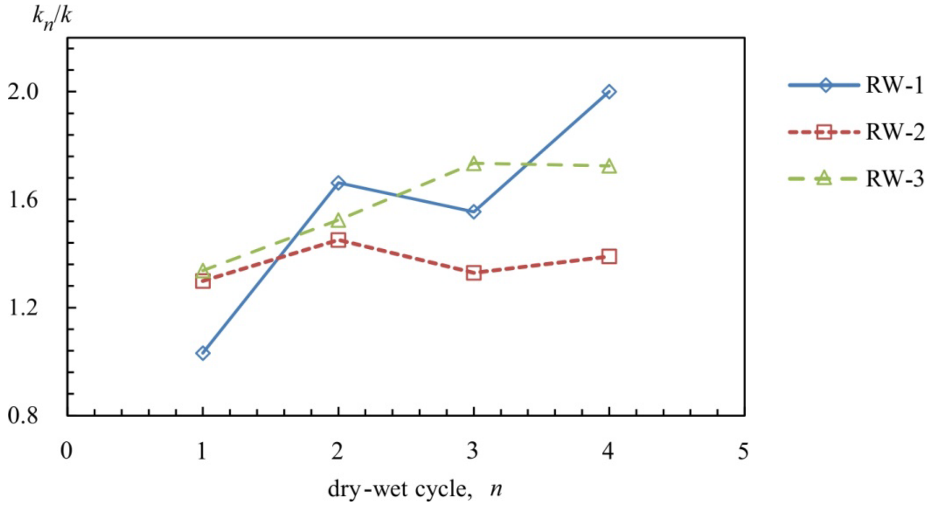

Fig. 6. Change of thermal conductivity with dry-wet cycle.

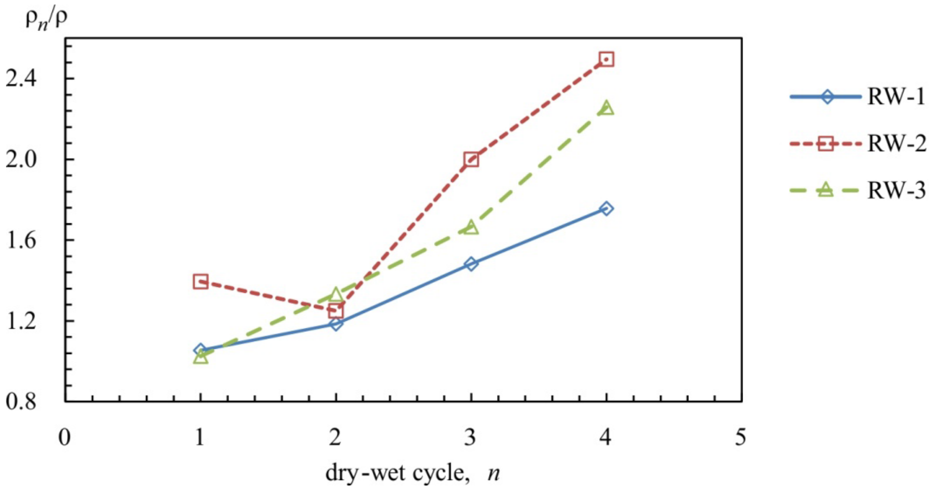

Fig. 7. Change of density with dry-wet cycle.

Conclusion

The effect of moisture content on the thermal conductivity of rock wool for three different manufacturers at different densities was investigated. The density of the insulating materials was changed by compressing them during measurement. The effect of wet-drying cycles on thermal conductivity and density was also investigated for three different manufacturers. The moisture content of the insulating material can significantly increase the thermal conductivity of the insulating material. The effect of moisture content is different depending on the density and manufacturer of the rock wool. The samples with higher density generally have large changes in thermal conductivity at the same moisture content. The thermal conductivity of the insulating material can increase from 1.33 to 4.42 times, depending on the density and the manufacturer of the rock wool. The thermal conductivity and density of the insulating material can increase up to 2 and 2.5 times, respectively, after 4 wet-drying cycles. The effect of wet-drying cycles is different depending on the rock wool manufacturer. The difference in the results obtained for different manufacturers of rock wool is possibly due to the difference in the manufacturing process.

Acknowledgments

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