Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 63 (2022) 1074–1080

Transportation Research Procedia

www.elsevier.com/locate/procedia

X International Scientific Siberian Transport Forum

Insulation thermal conductivity heating networks during transportation thermal energy under dry and moisturizing condition: a comparative study of the guarded hot plate and guarded hot pipe method

Aidar Hayrullin[a,]*, Aigul Haibullina[a], Alex Sinyavin[a]

[a]*Kazan State Power Engineering Univercity, Kazan, 420066, Russia*

Abstract

Due to the length of the thermal networks in Russia, the quality of the insulating materials of the pipeline systems is essential in the transportation of thermal energy. Incorrect thermal characteristics assessment of the heating networks insulating materials can lead to significant energy losses.In this paper, the thermal conductivity of rock wool at a temperature of 25 °C is determined by an experimental method. The density of the samples was 80 and 105 kg/m3. The thermal conductivity of rock wool was obtained on dry samples and with a moisture content of 5% by weight. The thermal conductivity of the insulation was obtained using the guarded hot plate and guarded hot pipe method. The results obtained by two different methods were compared with each other. Differences between rock wool thermal conductivity obtained by two methods were 3 and 9% at a density of 80 and 105 kg/m3. The differences were 8 and 6% for wetted insulation at a density of 80 and 105 kg/m3, respectively, while the thermal conductivity increased to 94%.

*Keywords:*Thermal conductivity of insulation; guarded hot pipe; guarded hot plate; rock wool.

1. Introduction

Due to the extensive territories of Russia, a large amount of energy is spent on the transportation of various energy resources. Therefore, even a slight increase in the efficiency of energy transportation can lead to a significant energy saving effect (Romanov et al., 2020). Energy-saving during the transportation of various energy resources

* Corresponding author. Tel.: +7-902-053-2363.
E-mail address: kharullin@yandex.ru

10.1016/j.trpro.2022.06.109

can be achieved by reducing heat losses. Thermal insulation reduces heat losses during energy transportation in heating and cooling systems. Heat losses depend on the characteristics of the insulating material their appropriate choice and calculation (Dolgova et al., 2020; Keçebaş et al., 2011). Insulating material characteristics can change significantly under environmental conditions (Karamanos et al., 2008; Parracha et al., 2022; Zhou et al., 2019). Heat loss may increase with increasing ambient temperature and humidity. Moisture penetration into the insulation material has a more significant effect on the increase in heat loss than temperature rise (Jerman and Černý, 2012). (Abdou and Budaiwi, 2013) measured the thermal conductivity of various insulation materials under humid conditions. The measurements were carried out on flat samples at different temperature and humidity levels. The maximum increase in thermal conductivity was observed for rock wool and mineral wool among the considered materials. The thermal conductivity of rock and mineral wool increased by 5.42 and 4.84 times, respectively, at a moisture content (MC) of 33.6% by mass and a temperature of 34 °C. (Jerman and Černý, 2012) presented the experimental results on the effect of moisture content on the thermal conductivity of flat slab insulating materials. The authors have shown that the thermal conductivity of mineral wool can increase up to 0.10–0.14 W/m·K at a moisture content of 5–20% by volume. (McFadden, 1988) determined the thermal conductivity of insulating materials at various moisture contents by volume. The thermal conductivity of polystyrene foam increased 2.4 times at a moisture content by a volume of 7%. The thermal conductivity of molded polystyrene increased 1.17 times compared to a dry sample at a moisture content of 10% by volume. (Wijeysundera et al., 1993) proposed an analytical method for determining the effective thermal conductivity of water vapor transfer through flat slab insulations material. The authors have shown that the effective thermal conductivity of the insulation can increase from 1.5 to 15 times compared to the dry state. (Alvey et al., 2017) experimentally determined the thermal conductivity of various insulating materials under different humidity levels. The effect of moisture on thermal performance was not significant for extruded polystyrene foam. Less than 10% of aerogel blankets degrade the thermal performance of polyurethane foam by less than 5%. (Gusyachkin et al., 2019) measured the thermal conductivity of rock wool of the same density from different manufacturers at different moisture content levels. The thermal conductivity of insulating materials increased with increasing moisture content. The effect of moisture content in insulating materials differed depending on the rock wool manufacturer. The rock wool thermal conductivity increased from 1.81 to 4.32 times depending on the rock wool manufacturer at a temperature of 26.7 °C and moisture content by weight of 13.6%. (Li et al., 2020 investigated the freeze-thaw cycle effect on the thermal conductivity of polyphenolic and polyurethane insulation boards. The thermal conductivity of the polyphenolic insulation material 1.5 times after 50 freeze-thaw cycles. The thermal conductivity of polyurethane insulation increased only 1.02 times under the same conditions. (Cai et al., 2014) measured the thermal conductivity of pipe phenolic insulation during moisture condensation. The thermal conductivity of phenolic insulation increased 1.4 times at a moisture content of 4.9% by volume. (Zhu et al., 2015) investigated the effect of wet condensing on the thermal conductivity of six fiberglass pipe insulations. The maximum increase in the thermal conductivity of fiberglass with moisture penetration was 3.51 times at a moisture content of 15% by volume.

The above review shows that the thermal conductivity of insulating materials, both under dry and wet conditions, is mainly determined on flat slab samples. There are only a few works in which the thermal conductivity of insulating materials is determined on pipe samples, especially under moisture content conditions. The guarded hot plate (GHP) method ISO 8302 (1991b) and the heat flow meter (HFM) method ISO 8301 (1991a) are mainly applied to measure the thermal conductivity of flat insulating materials. The HFM is used for both flat insulation and pipe insulation system. In a pipe insulation system, the guarded hot pipe method ISO 8497 (1994) is used to determine the thermal conductivity. In a pipe insulation system, pipe sleeve insulation is used, installed on the insulated pipe. However, slab insulation materials are also used when the slab wraps around the pipe. When using slab insulation in a pipe insulation system, thermal conductivity can be determined using the GHM. However, the thermal conductivity of an insulating material determined by the GHM and the guarded hot pipe method can lead to different results (Cai et al., 2014). This paper presents the results of measuring the thermal conductivity of rock wool using the GHM and the guarded hot pipe method. The results of thermal conductivity measurements were obtained for both dry and wetted samples. From the best knowledge of the authors, there are no papers in the open literature that investigate rock wool thermal conductivity using the GHP method and guarded hot plate for the conditions presented in this paper.

Nomenclature

GHP	guarded hot plate
HFM	heat flow meter
MC	moisture content
MW	mineral wool
RW	rock wool

2. Methodology and measurement apparatus

For the aim of the investigation, samples of rock wool with two different densities, 80 kg/m^3 (RW-80) and105 kg/m^3 (RW-105) were prepared. The thickness of the insulating material was 40 mm. The dimensions of the insulation were prepared depending on the measurement method used. When using the GHP, the rock wool dimensions were 150x150 mm, while using the guarded hot pipe method, they were approximately 530x1440 mm.

A standard instrument was used to measure the thermal conductivity of rock wool according to the GHP method (fig. 1). The device consists of a heated upper plate and a lower cooled one. The insulating material is placed between two plates. The temperature of the upper and lower plates correspond to 35 and 15 °C. All measurements are carried out at an average insulation temperature of about 25°C. Moisturizing of the insulation was carried out by injection method (Cai et al., 2014). Moisture was injected uniformly over the sample surface.

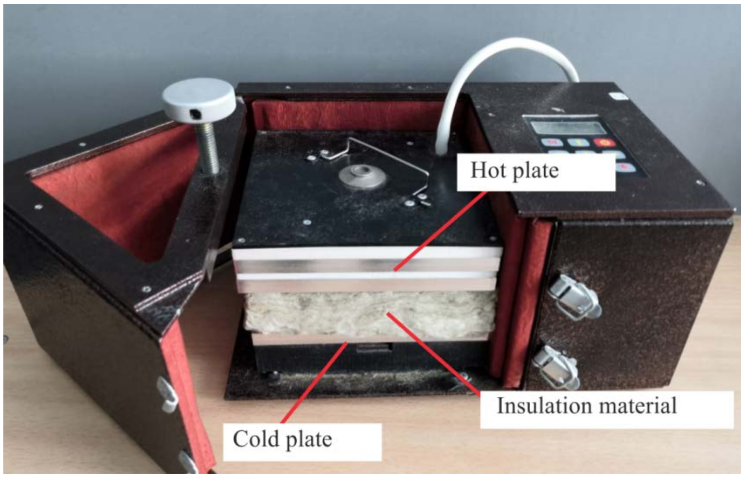

Fig. 1. Experimental apparatus. Guarded hot plate.

Measurements by the guarded hot pipe method were carried out on an experimental setup made by the authors (fig. 2). The measuring section consists of a pipe with a length of 1440 mm and an outer diameter of 89 mm. The pipe is heated from the inside with film heaters. The pipe is divided into three equal sections, the working zone, the left and the right guarded zone. The heating power of each of the three zones is regulated separately. The location of the temperature sensors on the pipe surface is shown in fig. 3. The thermal conductivity of the insulating material is determined by the working area. Guard zones prevent heat leakage in the axial direction. The outer wall temperature of the pipe was maintained at about 35 °C. Rock wool was wrapped around the pipe. Moistening of the material was carried out on the wrapped insulation by injection. A coiled tube was installed on the pipe insulation. Coldwater circulated through the coiled tube. The outer surface temperature of the testing insulating material was about 15 °C. The coiled tube was wrapped with an additional layer of insulating material (fig. 4).

Fig. 2. Experimental apparatus. Guarded hot pipe.

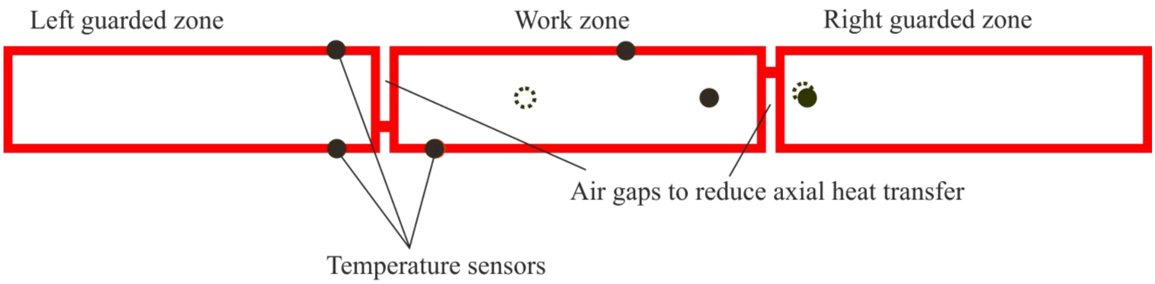

Fig. 3. Scheme of temperature sensors.

Fig. 4. Experimental investigation of thermal conductivity. Rock wool insulation wrap around hot pipe.

3. Results and discussion

The thermal conductivity of flat slab rock wool samples was obtained using the GHP method, slab wrapped on a pipe using the guarded hot pipe method. Samples were prepared from the same rock wool roll. The rock wool density was 80 and 105 kg/m^3, the average temperature of the samples was 25°C, the temperature difference between the cooled and heated sides of the insulation was 20°C. Thermal conductivity was determined for dry samples and moistened to 5% by weight. The thermal conductivity experimental error was less than ±8%.

Table. 1 shows the results of an experimental study. Figure 5 compares the thermal conductivity obtained by the GHP method and the guarded hot pipe method for dry samples. The results obtained in this work are compared with the experimental data of other authors. As can be seen from Figure 5, the results obtained in this work coincide with the data of other authors. The thermal conductivity of flat slab samples is in the range of (0.0351-0.0397) W/m·K. The thermal conductivity of samples determined by the guarded hot pipe method is in the range of (0.0328-0.043) W/m·K. The differences in the thermal conductivity coefficient values can be explained by the error of experimental data, the difference in density, and the difference in the manufacturing process of insulating materials. The thermal conductivity of mineral wool with the same density may differ due to the difference in binding agents. The maximum difference in the thermal conductivity values of flat samples of 13% is observed between RW-105 and the data (Abdou and Budaiwi, 2013) for rock wool with a density of 46 kg/m^3, which is 2.3 times less than the density of RW-105. The obtained difference in thermal conductivity values of insulations determined by the guarded hot pipe method is higher than the GHP method. The maximum difference of 24% between the data of this work and other authors is observed for RW-80 and the data presented in (Cai et al., 2014).It should be noted that (Zehendner, 1983) and (Cai et al., 2014) provide data on the thermal conductivity of mineral wool pipe sleeves installed on the hot pipe. In the present study, slab rock wool was wrapped around the pipe. The thermal conductivity values of the insulation obtained by the two methods in this study are in better agreement with each other, compared with the data of other authors. The better agreement of the thermal conductivity values obtained in this study can be explained because the samples were prepared from the same roll of rock wool. In this way, possible differences in the production process in the manufacture of insulation (use of different binders, etc.) were excluded. The difference in thermal conductivity between the two methods for RW-80 and RW-105 was 3% and 9%, respectively.

Figure 6 shows the results of thermal conductivity measurements when the insulation is moistened, obtained by the GHP method and guarded hot pipe. The thermal conductivity of the insulation at MC 5% by mass increases with both the GHP and the guarded hot pipe method. Thermal conductivity is higher for insulation with a higher density of 105 kg/m^3. The thermal conductivity of RC-105 increased by 94% with GHP and by 88% with the guarded hot pipe. As for dry insulation, the thermal conductivity of wetted insulation obtained by the two methods is in good agreement with each other. The differences between the thermal conductivity values were 8 and 6% for RW-80 and RW-105, respectively.

Table 1. Thermalconductivitymeasurementresultsof rock wool.

Sample code	Type	Mean temperature (°C)	Thermal conductivity (W/m-K)	MC by weight (%)	Density (kg/m3)
RW-80	Slab	25	0.0357	0	80
RW-105	Slab	25	0.0351	0	105
RW-80	Slab	25	0.0522	5	80
RW-105	Slab	25	0.0682	5	105
RW-80	Pipe	25	0.0348	0	80
RW-105	Pipe	25	0.0382	0	105
RW-80	Pipe	25	0.0562	5	80
RW-105	Pipe	25	0.0720	5	105

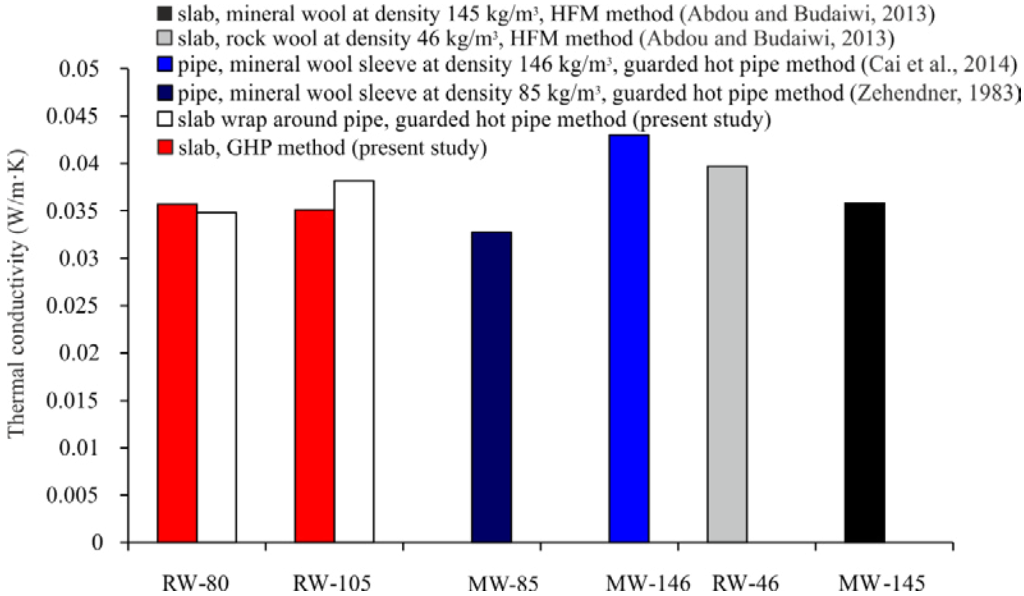

Fig. 5. Thermal conductivity comparison of dry samples studied in this work with the data of other authors.

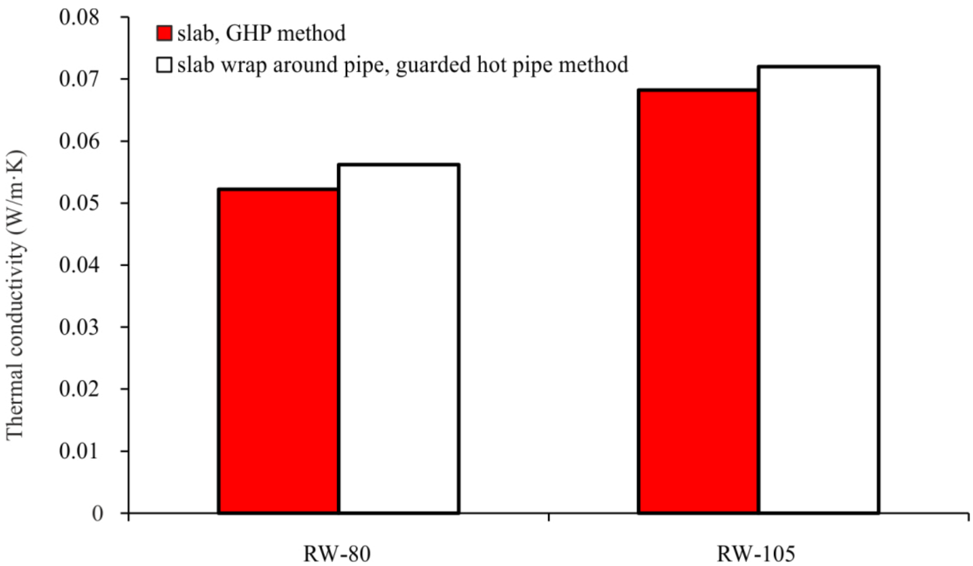

Fig. 6. Thermal conductivity of rock wool at MC 5% by mass.

4. Conclusion

The thermal conductivity of rock wool from the same roll was determined using the guarded hot plate and guarded hot pipe method. The guarded hot plate method was employed for flat slab samples. When the guarded hot pipe method was employed, insulation was wrapped around the pipe. A comparative experiment showed that the thermal conductivity obtained by the two methods is in good agreement with each other. Differences in thermal conductivity values were no more than 9%, which is within the error range of experimental studies. Thus, the thermal conductivity of rock wool from the same manufacture in the density range from 80 to 105 kg/m^3 and an average insulation temperature of 25 °C can be obtained by the guarded hot plate method instead of the more complex guarded hot pipe method. However, the results obtained by the two methods may differ under other experimental conditions (the type of insulation, density, thickness, average temperature, and temperature difference between the cold and hot side of the insulation). Therefore, further research is needed in this area.

Acknowledgements

The research was funded by the Russian Science Foundation, grant number № 21-79-10406, https://rscf.ru/en/project/21-79-10406/.

References

1991. ISO 8301, Thermal insulation - Determination of steady-state thermal resistance and related properties - Heat flow meter apparatus. Geneva, Switzerland: International Organization for Standardization.

1991. ISO 8302, Thermal insulation - Determination of steady-state thermal resistance and related properties - Guarded hot plate apparatus. Geneva, Switzerland: International Organization for Standardization.

1994. ISO 8497, Thermal Insulation - Determination of steady-state thermal transmission properties if thermal insulation for circular pipes. Geneva, Switzerland: International Organization for Standardization.

Abdou, A., Budaiwi, I., 2013. The variation of thermal conductivity of fibrous insulation materials under different levels of moisture content. Construction and Building Materials 43, 533–544. https://doi.org/10.1016/j.conbuildmat.2013.02.058.

Alvey, J.B., Patel, J., Stephenson, L.D., 2017. Experimental study on the effects of humidity and temperature on aerogel composite and foam insulations. Energy and Buildings 144, 358–371. https://doi.org/10.1016/j.enbuild.2017.03.070.

Cai, S., Cremaschi, L., Ghajar, A.J., 2014. Pipe insulation thermal conductivity under dry and wet condensing conditions with moisture ingress: A critical review. HVAC&R Research 20, 458–479. https://doi.org/10.1080/10789669.2014.882678.

Dolgova, A.N., Yunak, S.A., Rudenko, A.S., Haibullina, A.I., Karataeva, E.S., 2020. Comparative efficiency of pipeline heat-insulating materials. IOP Conf. Ser.: Mater. Sci. Eng. 915, 012010. https://doi.org/10.1088/1757-899X/915/1/012010.

Gusyachkin, A.M., Sabitov, L.S., Khakimova, A.M., Hayrullin, A.R., 2019. Effects of moisture content on thermal conductivity of thermal insulation materials. IOP Conf. Ser.: Mater. Sci. Eng. 570, 012029. https://doi.org/10.1088/1757-899X/570/1/012029.

Jerman, M., Černý, R., 2012. Effect of moisture content on heat and moisture transport and storage properties of thermal insulation materials. Energy and Buildings 53, 39–46. https://doi.org/10.1016/j.enbuild.2012.07.002.

Karamanos, A., Hadiarakou, S., Papadopoulos, A.M., 2008. The impact of temperature and moisture on the thermal performance of stone wool. Energy and Buildings 40, 1402–1411. https://doi.org/10.1016/j.enbuild.2008.01.004.

Keçebaş, A., Ali Alkan, M., Bayhan, M., 2011. Thermo-economic analysis of pipe insulation for district heating piping systems. Applied Thermal Engineering, SET 2010 Special Issue 31, 3929–3937. https://doi.org/10.1016/j.applthermaleng.2011.07.042.

Li, Y., Wang, H., Yang, L., Su, S., 2020. Study on Water Absorption and Thermal Conductivity of Tunnel Insulation Materials in a Cold Region under Freeze-Thaw Conditions. Advances in Materials Science and Engineering 2020, e5301968. https://doi.org/10.1155/2020/5301968.

McFadden, T., 1988. Thermal Performance Degradation of Wet Insulations in Cold Regions. Journal of Cold Regions Engineering 2, 25–34. https://doi.org/10.1061/(ASCE)0887-381X(1988)2:1(25).

Parracha, J.L., Borsoi, G., Flores-Colen, I., Veiga, R., Nunes, L., 2022. Impact of natural and artificial ageing on the properties of multilayer external wall thermal insulation systems. Construction and Building Materials 317, 125834. https://doi.org/10.1016/j.conbuildmat.2021.125834.

Romanov, D., Pelda, J., Holler, S., 2020. Technical, economic and ecological effects of lowering temperatures in the Moscow district heating system. Energy 211, 118680. https://doi.org/10.1016/j.energy.2020.118680.

Wijeysundera, N.E., Zheng, B.F., Iqbal, M., Hauptmann, E.G., 1993. Effective Thermal Conductivity of Flat-Slab and Round-Pipe Insulations in the Presence of Condensation. Journal of Thermal Insulation and Building Envelopes 17, 55–77. https://doi.org/10.1177/109719639301700206.

Zehendner, H., 1983. Thermal Conductivity of Thermal Insulation Materials on Pipes. Journal of Thermal Insulation 7, 52–68. https://doi.org/10.1177/109719638300700105.

Zhou, S., Ding, Y., Wang, Z., Dong, J., She, A., Wei, Y., Li, R., 2019. Weathering of Roofing Insulation Materials under Multi-Field Coupling Conditions. Materials (Basel) 12, 3348. https://doi.org/10.3390/ma12203348.

Zhu, W., Cai, S., Cremaschi, L., 2015. Thermal performance and moisture accumulation of fibrous mechanical pipe insulation systems operating at below-ambient temperature in wet conditions with moisture ingress. Science and Technology for the Built Environment 21, 862–875. https://doi.org/10.1080/23744731.2015.1056658.