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Thermal Conductivity Measurement for Liquid Substance by Thermoelectric Cooler Utilization

Tri Ayodha Ajiwiguna[1*], Riana Dewi[1], Mukhammad Ramdlan Kirom[1]

[1]*Department of Engineering Physics, Telkom University, Bandung, Indonesia.*

Abstract:

Thermal conductivity is one of the important thermal properties of the substance. In this study the method to measure thermal conductivity of liquid the substance was performed by adopting temperature gradient method. To avoid heat convection in the substance, temperature gradient was created by cooling the bottom of liquid substance using thermoelectric module. Stainless steel was used as the reference material and water as tested material. The thickness of tested material was varied from 5 mm to 15 mm with 5 mm of increment in the experiment. The results show that the lowest error was obtained from the 15 mm thickness with 2.8 % error. The lowest uncertainty was observed in 10 mm of thickness with 9% of standard deviation.

INTRODUCTION

Thermal conductivity is thermal properties that measure the ability of substance to conduct heat. The information of thermal conductivity value of material helps engineer and researcher to select material required for applications. The thermal conductivity of liquid substance is enhanced when suspended nanoparticles in it, called nanofluids [1]. The applications of high thermal conductivity fluids can improve the heat performance in engineering system [2]. Based on this fact, the measurement of thermal conductivity of liquid substance becomes important.

There are several methods to measure thermal conductivity of the substance [3-8]. One of them is adopting the temperature gradient method to the tested substance. The utilization of thermoelectric module as a heater for this method to measure thermal conductivity of solid substance has been reported with reasonable result [9]. In liquid substance, the heat convection should be avoided to assure that only heat conduction flow through the material.

In this study, the experiment to measure thermal conductivity of liquid substance using temperature gradient method was conducted. Instead of heating from the bottom of tested material, cooling was applied by using thermoelectric module to avoid heat convection. The error of measurement was analyzed by comparing the result with the value of thermal conductivity from the reference. While, the uncertainty of measurement was obtained from the standard deviation of measurement result.

EXPERIMENTAL SETUP

In this study, the scheme of experimental setup is shown in figure 1. The tested material was water inside a container. The insulation layer was attached on the container wall to assume that heat flow only at vertical direction. Reference material in this experiment was stainless steel SS304 since its thermal conductivity is well known and was put at the bottom of tested material. The dimension of reference material was 40 x 40 x 20 mm. The cold side of thermoelectric cooler was contacted to the bottom of reference material with the same surface area with reference substance. Heat sink-fan was attached on the bottom of thermoelectric module to avoid overheating condition during experiment.

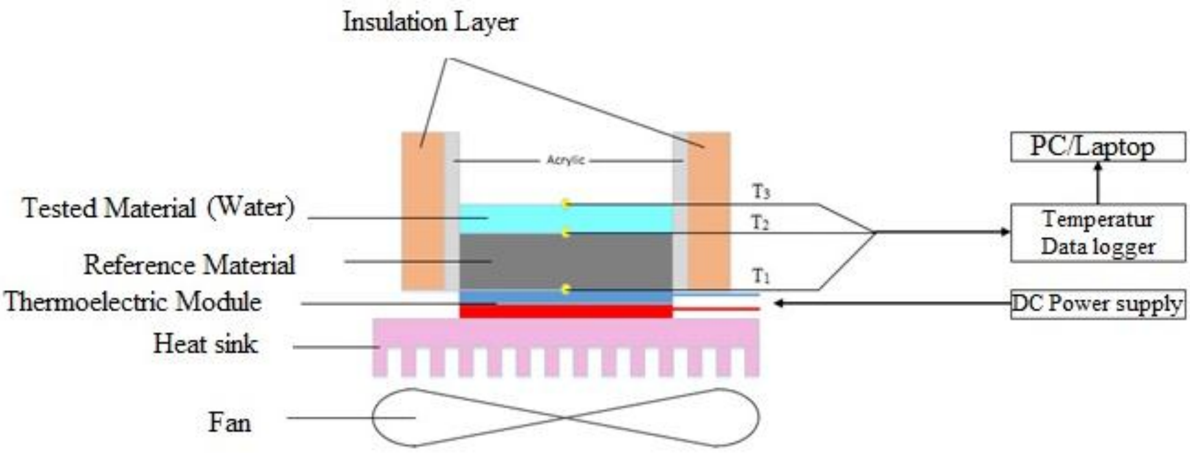


Figure 1. Experimental setup scheme

DC electrical current was supplied to the thermoelectric module thus the cold side absorbed heat from the top and the hot side emitted heat to ambient through heatsink. The temperature at T1, T2, and T3 were measured using T-type thermocouple and was recorded using temperature data logger. The thickness of tested material varies from 5 mm to 15 mm for comparison.

Once DC electric current was supplied to the thermoelectric module the temperature gradient occurred and was measured after steady state condition established. Since the heat flow is mainly at vertical direction from the top of tested material to bottom of reference material, so the heat conduction at tested material and reference material was the same.

$$k_{ref}\frac{A_{ref}(T_2 - T_1)}{L_{ref}} = k_t\frac{A_t(T_3 - T_2)}{L_t} \quad (1)$$

Where k_{ref}, A_{ref}, and L_{ref} were thermal conductivity, area, and thickness of reference material respectively. On the other hand, k_t, A_t, and L_t were thermal conductivity, area, and thickness of tested material respectively.

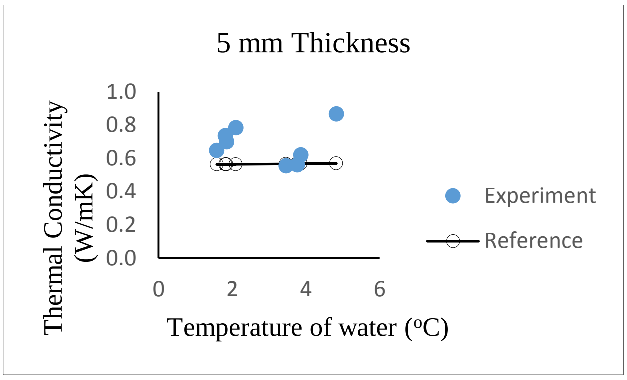
Since the thermal conductivity of reference material was known, area of tested and reference material were the same, and other variables were measurable, so the thermal conductivity of tested material was calculated by:

$$k_t = \frac{L_t(T_2 - T_1)}{L_{ref}(T_3 - T_2)}k_{ref} \quad (2)$$

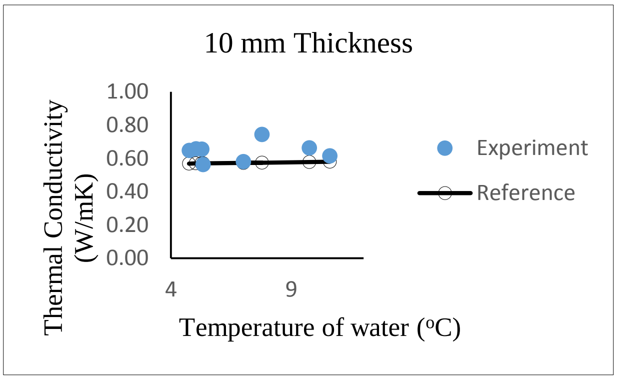
This experimental results were then compared with the value of thermal conductivity of water based on M. L. V Ramires measurement results [10]. Temperature dependence of thermal conductivity from 2 oC to 52 oC was very linear with the value of R2 of 0.9915 and followed the linear regression equation below:

$$k_w = 0.0017T + 0.5615 \quad (3)$$

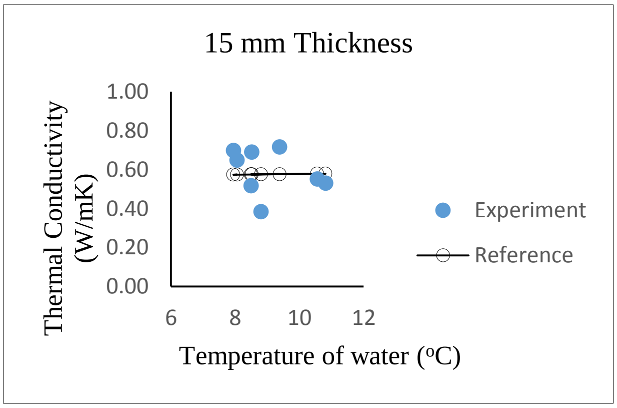
Where k_w is thermal conductivity of water (W/mK) and T is the temperature of water (°C).



(a)



(b)



(c)

Figure 2. Experimenta result and reference value: (a) 5 mm thickness,(b) 10 mm thickness, (c) 15 mm thickness

RESULT AND DISCUSSION

The experiment results is plotted in figure 2. The temperature (x axis) means the average temperature between the bottom and surface of tested material. Black line with circles is the reference value of thermal conductivity of water calculated by using equation 3.

Table 1 shows the error and the standard deviation of measurement. The errors are obtained by comparing between experiment result and reference. The higher error means the experiment creates larger difference value with the reference. It shows the error of measurement decreases with the thickness of tested material. The highest error is observed 5 mm thickness with the error of 20.8%. While, the lowest error comes from 15 mm thickness with the error of 2.8%. The upper surface of water inside container is not perfectly flat due to meniscus phenomena. The adhesion of water which is stronger than its cohesion causes the concave meniscus [11]. It causes error measurement in the experiment. The effect of meniscus to the thickness of tested material is relatively less significant at the thicker tested material.

Table 1. Comparison result between experiment and reference

Thickness (mm)	Measurement result (W/mK)	Reference Value (W/mK)	Standard deviation (%)	Error (%)
5	0.685	0.566	16	20.8
10	0.641	0.573	9	11.9
15	0.593	0.577	19	2.8

The standard deviation of measurement indicates the uncertainty of measurement. The highest standard deviation is in 5 mm thickness. In this experiment the temperature difference between the bottom and upper surface of tested substance is very small. It causes relatively high uncertainty of temperature difference which is used for thermal conductivity calculation. The thickness of 10 mm results the lowest standard deviation. However in the 15 mm thickness, the standard deviation increases again. The effect of cooling by thermoelectric module decreases with the thickness of tested substance. Since the top surface contacts with the ambient air so its temperature is easily changed and causes the uncertainty of measurement.

CONCLUSSION

In this study, the experimental for thermal conductivity measurement of liquid substance by employing thermoelectric module is well conducted with reasonable accuracy and uncertainty. The most accurate measurement is observed in 15 mm thickness of tested material with the error of 2.8% from the reference value of thermal conductivity. The lowest uncertainty of measurement is in 10 mm of thickness with standard deviation of 9%. The study can be improved by investigating the optimum thickness of tested substance to obtain the highest accuracy and lowest uncertainty measurement.

REFERENCES

[1] W. Yu, D. M. France, J. L. Routbort, and S. U. Choi, 2008, “Review and comparison of nanofluid thermal conductivity and heat transfer enhancements,” Heat Transfer Engineering, Vol 29, pp. 432-460.

[2] S. Jana, A. Salehi-Khojin, and W.-H. Zhong, 2007, “Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives,” Thermochimica acta, Vol. 462, pp. 45-55, 2007.

[3] K. D. Antoniadis, G. J. Tertsinidou, M. J. Assael, and W. A. Wakeham, 2016, “Necessary Conditions for Accurate, Transient Hot-Wire Measurements of the Apparent Thermal Conductivity of Nanofluids are Seldom Satisfied,” International Journal of Thermophysics, Vol. 37, pp. 1-22,

[4] V. Bohac, M. K. Gustavsson, L. Kubicar, and S. E. Gustafsson, 2000, "Parameter estimations for measurements of thermal transport properties with the hot disk thermal constants analyzer,” Review of Scientific Instruments, Vol. 71, pp. 2452-2455.

[5] C. H. Li and G. Peterson, 2007, “The effect of particle size on the effective thermal conductivity of Al2 O 3-water nanofluids,” Journal of Applied Physics, Vol. 101, p. 044312.

[6] Robert A. Miller and Maria A. Kuczmarski, 2009, “Method for Measuring Thermal Conductivity of Small Samples Having Very Low Thermal Conductivity,” NASA/TM 215460.

[7] C. Buratti, E. Belloni, L. Lunghi, A. Borri, G. Castori, M. Corradi, 2016, “Mechanical characterization and thermal conductivity measurements using of a new 'small hot-box' apparatus: innovative insulating reinforced coatings analysis”, Journal of Building Engineering Volume 7, pp. 63–70.

[8] W. Parker, R. Jenkins, C. Butler, and G. Abbott, 1961, “Flash method of determining thermal diffusivity, heat capacity, and thermal conductivity,” Journal of applied physics, vol. 32, pp. 1679-1684,.

[9] T. A. Ajiwiguna, S. Y. Kim, 2016, “Thermal conductivity measurement using thermoelectric module”, J. Phys.: Conf. Ser. 776 012098

[10] Maria LV Ramires, Carlos A Nieto de Castro, Yuchi Nagasaka, Akira Nagashima, Marc J Assael, William A Wakeham, 1995, “Standard reference data for the thermal conductivity of water”, Journal of Physical and Chemical Reference Data, 24 (3), pp 1377-1381.

[11] John Polansky, Tarik Kaya, 2018, “Experimental investigation of thermally driven meniscus instability in capillary tubes”, International Journal of Heat and Mass Transfer Vol 117, pp. 458-464.