Research and development of measurement device for thermal conductivity of nanofluids

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Abstract. This research aims to develop a device for measuring thermal conductivity of nanofluid using transient hot-wire methodology. The proposed measurement system comprises of sensing wires coupled with an electrical measurement unit kept in a constant-temperature environment. The wires are made of nickel-chromium alloy a coating with Teflon for insulation. Enhanced ratio of thermal conductivity in a nanofluid is calculated from the difference in electrical parameters with and without CuO nanoparticles added. The results show that thermal conductivities are enhanced by 5.8% and 9.6% when CuO nanoparticles of 1.1%wt and 2.2%wt are added, respectively. Resultant data was then compared with that obtained by two other measurement devices. The difference in measurements was within 5%. This proves that the system developed in this study can perform effective measurement of thermal conductivity of nanofluids.

1. Introduction
Nanofluid is a novel solid-liquid suspension consisting of nanoparticles and a base liquid. Previous research has shown that adding nanoparticles to fluid can effectively increase the thermal conductivity of the nanofluid [1-4]. Nevertheless, each nanofluid has its unique characteristics and there is no single estimation model or calculation formula that can be applicable to all nanofluids [5,6]. In view of this, experimental measurement of thermal conductivity of nanofluids may be a more direct method of greater accuracy.

The transient hot-wire method is one of the important means for measuring thermal conductivity. It has been widely employed to measure thermal conductivity of nanofluids [7-9]. Following the principles of the transient hot-wire method, this study develops a device for measuring thermal conductivity of nanofluids using sensing wires made of nickel-chromium alloy and covered with Teflon. Compared with platinum wire, nickel-chromium alloy wire is less expensive, can be changed easily at any time and can avoid errors when measuring electric conductivity of fluid.

2. Theory and Experimental Design
The transient hot-wire method is often employed to measure thermal conductivity. The governing equation of the transient hot-wire method can be expressed as equation (1):

\[ T(t) - T_i = \frac{q}{4\pi k} \ln \left( \frac{4D}{r^2C} \right) \quad (1) \]

where \( T(t) \) is the temperature of the wire in the fluids at time \( t \), \( T_i \) is the initial temperature of the fluid in the container, \( q \) is the input power per meter of sensing wire, \( k \) is the thermal conductivity, \( D \) is the thermal diffusivity of the fluid, \( r \) is the radius of the sensing wire, and \( \ln C \) is Euler’s constant. Assuming that there exists a linear relationship between changes in \( \ln t \) and temperature, thermal conductivity \( k \) can be calculated according to Fourier’s principle as follows:

\[ k = \frac{q}{4\pi(T_2 - T_1) \ln \left( \frac{t_2}{t_1} \right)} \quad (2) \]

where \( q \) can be taken as the input power per meter of sensing wire, \( t_1 \) and \( t_2 \) both denote time, \( T_1 \) and \( T_2 \) are temperatures. At the same measurement time, the thermal conductivity to be calculated is in direct proportion to the average input power \( q_{\text{avg}} \) and difference in temperature \( dT \). Changes in temperature of the sensing wire are directly proportional to the electrical resistivity, whose changes can also be expressed as changes in output voltage \( dV_{\text{out}} \). Hence, equation (2) can be rewritten as follows:

\[ k \propto \frac{q_{\text{avg}}}{dV_{\text{out}}} \quad (3) \]

Figure 1 shows the setup of the proposed device for thermal conductivity measurement. The nickel-chromium alloy sensing wire of 0.2 mm diameter was covered with Teflon for insulation. The wire was fixed on the glass fiber holder and immersed vertically into the sensing unit containing 100 ml. of nanofluids specimen. The whole measuring unit was connected to a heating and refrigerating circulator to maintain constant temperature at 30°C.

The specimens used in this experiment were deionized water and nanofluids containing 1.1%wt and 2.2%wt of CuO nanoparticles with an average diameter of 85 nm, which were manufactured by the submerged arc nanoparticle synthesis system (SANSS). Each type of specimen was measured 20 times, each lasting 10 sec. The measurement time should be kept short to avoid convection which may undermine the measurement accuracy. With the average input power and output voltage from the Wheatstone bridge, the ratios of the electrical parameter of the nanofluids and the base liquid can be obtained respectively from the equation (3), and then the enhanced ratio of thermal conductivity can be calculated from the ratio of those.

![Figure 1. The proposed measurement device](image)

3. Results & Discussion

Figures 2 and 3 show the measurement results. As can be seen, the trend of both output voltage and input power began to reverse at 8 sec. There exists a linear correlation between temperature and...
thermal conductivity; hence, we take only the average power input, \( q_{\text{avg}} \), and difference in output voltage, \( dV_{\text{out}} \), of 1-6 sec for calculation.

Figure 2 displays the input power of the sensing wire. As shown, deionized water has lower input power than nanofluids. Under the same voltage, low input power implies high resistivity of the sensing wire which also means high temperature and low thermal conductivity. Figure 3 shows the output voltage of the specimens. High thermal conductivity implies better heat dissipation. Within a fixed time, smaller changes in temperature of the sensing wire and resistivity would result in smaller difference in output voltage.

Figure 2. Input power of different specimens

![Figure 2. Input power of different specimens](image)

Figure 3. Output voltage of different specimens

![Figure 3. Output voltage of different specimens](image)

| Measurement device | 1.1% wt CuO nanofluids | 2.2% wt CuO nanofluids |
|--------------------|-------------------------|-------------------------|
| Enhanced thermal conductivity ratio, %\(^a\) | A 5.82 | B 6.12 | C 5.73 | A 9.62 | B 9.83 | C 9.75 |
| Error %\(^b\) | — | 4.90 | -1.57 | — | 2.14 | 1.33 |

\(^a\) A denotes the proposed measurement device, B denotes the thermal conductivity of liquids and gases unit (P.A. Hilton H470), and C denotes the thermal properties meter (Decagon KD2).

\(^b\) Error % denotes the difference in measurement results obtained by A compared with B and C, respectively.
As seen in Table 1, the thermal conductivity of the 1.1%wt and 2.2%wt CuO nanofluids were enhanced by 5.8% and 9.6%, respectively. Figure 6 shows the comparison of measurements obtained by the three different measurement devices, revealing that the difference is within ±5%.

4. Conclusion
From the above results and analysis, we can conclude that the presence of nanoparticles can indeed enhance the thermal conductivity of fluids. The proposed measurement device has been proved to be a reliable and effective tool for measuring thermal conductivity of nanofluids.

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