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A RESEARCH ON MEASUREMENT TECHNIQUES OF APPARENT THERMAL CONDUCTIVITY OF NANOFLUIDS THERMAL

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Abstract. Thermal conductivity of nanofluids has been extensively studied for a number of years because it is a very first evaluation of the heat transfer performance of nanofluids. However, not the single theoretical model predicts thermal conductivity of nanofluids accurately. Hence, different measurement techniques have been used to measure thermal conductivity of nanofluids. This paper focuses on different measurement techniques of thermal conductivity of nanofluids. The working principle, limitation and advantages of different measurement techniques have been discussed. The measurement techniques discussed in this paper included transient hot wire, transient plane source, 3-omega technique, steady-state parallel method, thermal comparator and laser flash method. Eventually, some suggestions have been made for improving the reliability of the measurement of thermal conductivity.

1. Introduction

A nanofluid is a fluid contains suspended nanoparticles typically in size from 1 to 100nm [1, 2]. With the presence of nanoparticles, thermal conductivity of nanofluids is enhanced significantly when compare to fluids without suspended nanoparticles [3]. Application of high thermal conductivity of nanofluids brings promising hope to industry by reducing the energy consumption and enhance heat transfer performance of engineering system [2]. Hence, the worldwide thermofluids enthusiast has launched research on nanofluids as a potential alternative for traditional heat transfer fluids. Thermal conductivity of nanofluids has been extensively studied for a number of years because it is a very first evaluation of the heat transfer performance of nanofluids [3]. The thermal conductivity of nanofluids is one of the significant parameters which influences convective heat transfer of nanofluids [4]. There are many theoretical models have been proposed to predict thermal conductivity of nanofluids. However, not the single theoretical model predicts thermal conductivity of nanofluids accurately [5, 6]. Hence, different

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measurement techniques have been used to measure thermal conductivity of nanofluids.

A number of researchers have reported different measurement techniques for study apparent thermal conductivity of nanofluids. The measurement technique included transient hot-wire, transient plane source, 3-omega techniques, steady-state parallel plate, thermal comparator, laser flash method and etc. Experiments reveal anomalous enhancements of thermal conductivity of nanofluids have been observed. The anomalous enhancement of thermal conductivity of nanofluids has been the subject of intense debate within the scientific community. Lee, et al. [7], Choi, et al. [8], Eastman, et al. [9] and Chopkar, et al. [10] have been reported anomalous enhancement with a nonlinear relationship with increases volume fraction of nano particles.

2. Apparent thermal conductivity measurement technique for nanofluids

2.1 Transient hot-wire

Transient hot-wire (THW) determines the thermal conductivity of material sample based on investigation of the transient temperature rise of a thin, vertical, long and resistive wire (Rw) immersed in fluid sample [12]. The wire (Rw) originally in thermal equilibrium to surrounding and a step current is passed through the wire. The wire (Rw) is heated up and time-dependent temperature field inside the wire and material sample is produced. Then, the thermal conductivity of fluid sample can be calculated from the gradient of temperature rise of wire versus natural logarithms of time graph. The temperature rise of wire is normally measured from Wheatstone bridge and an A/D converter is used to convert analog data to digital data then store in computer for further analysis. A schematic diagram of transient hot-wire is shown as Figure 1.

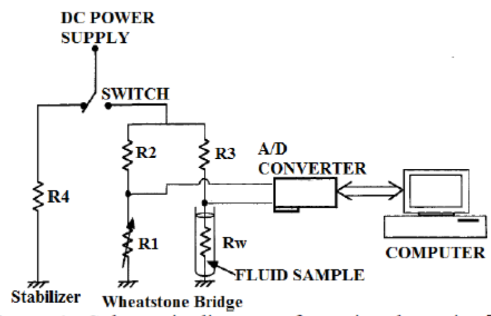

Figure 1. Schematic diagram of transient hot-wire [7]

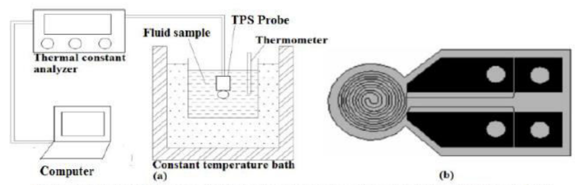

Figure 2. Schematic diagram of TPS device: (a) Experiment setup for TPS (b) TPS probe [24]

The TPS has been used by Zhu, et al. [25], Jiang, et al. [24], Zhi, et al. [26], Wan, et al. [27] and Nikkam, et al. [28] for measuring apparent thermal conductivity of nanofluids. The TPS able detects occurrence of natural convection by examining experiment data. If natural convection is occurring, the experiment data would not fit in the graph, hence, the measurement is not accurate. In this particular case, the thermal analyzer would give an alarm to prevent using the inaccurate data. Furthermore, TPS can use to measure a wide range of thermal conductivity typically from 0.02W/mK to 200W/mK andthe sample size is flexible whereby no need sample preparation [25]. However, TPS cannot use to measure

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thermal conductivity of fluid which undergoes the boiling process. Because the temperature maintains constant at this process whereby not temperature rises can be detected.

Based on Oh, et al. [31], the thermal conductivity of the nanofluids can be measured by 3ω technique even though, in single droplet volume size. Besides that, the gravitational effect on nanofluids also can be studied by altering the orientation of the device. Furthermore, the stability of nanofluids also can study by this device observe the thermal conductivity enhancement due to sedimentation of nanoparticles. However, 3ω technique has a significant drawback when measure nanofluids with lower thermal conductivity and heat capacity. In this regard, less heat is flowing from metal strip to fluid as compared to the solid substrate with high thermal conductivity and heat capacity. This cause the 3ω signal from solid substrate more significant than fluid, hence reduce the precision of the device.

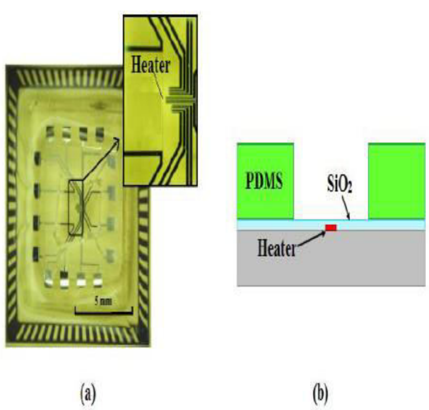

Figure 3. Schematic of an experimental set up for 3-omega method: (a) top view of the device and (b) side view of the device (not to scale) [31]

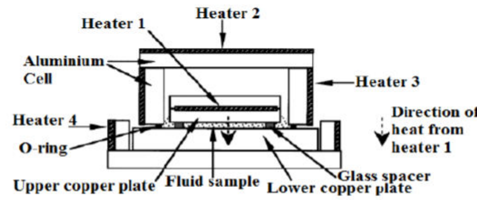

Figure 4. Schematic experimental setup for steady state parallel plate [35]

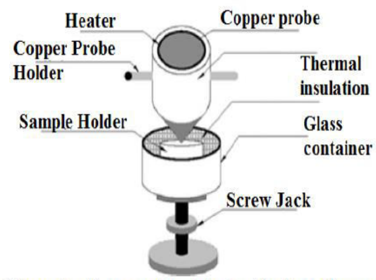

Figure 5. Schematic of an experimental setup for thermal comparator [37]

TC is a very sensitive device to measure thermal conductivity of nanofluids. This technique can measure thermal conductivity at the instant just by making a point contact between probe and testing sample. Thus, convection of fluid during the experiment can be avoided and improved the precision of the device. The drawback of this technique is required to do a lot work to calibrate the device. Difference liquids with known thermal conductivity have been used to obtain their comparator reading respectively. With this set of data, a calibration curve can be obtained and thermal conductivity of testing sample can be obtained by comparing the comparator in the calibration curve. However, once the calibration curve is plotted out, the thermal conductivity of testing sample can be obtained just by referring to the comparator reading.

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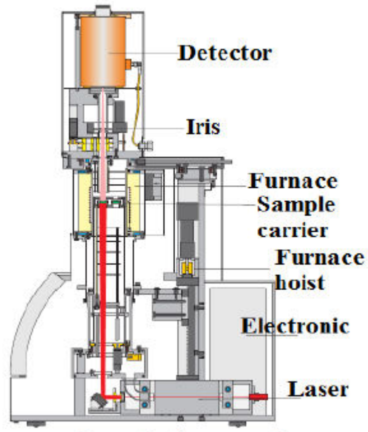

Figure 6. Schematic diagram of LFA457 [39]

3. Discussion

A literature survey has been done on the six measurement techniques which have discussed in this review paper. Based on table 1, THW is the most frequently used measurement technique for nanofluids compared to other techniques due to its well known reputation. On the other hand, steadystate parallel method is the least popular among measurement techniques, although the design of this method is simple and easy to use. This is because steady-state parallel method natural has high tendency occurs natural convection during the measurement process, thus make the measurement result less accurate.

Table 1. Comparison of the measurement techniques for nanofluids

Measurement technique	Published literature (%)
Transient hot-wire	51.72
Transient plane source	20.69
3-omega technique	8.62
Steady-state parallel method	5.17
Thermal Comparator	6.90
Laser flash method	6.90

There are two aspects have been concerned when come into thermal conductivity measurement for nanofluids. Firstly, the required time range of measurement is one of the important aspects have been concerned especially for thermal conductivity measurement of nanofluids because long measurement time range will induce natural convection and eventually affect the measurement result. Among these six measurement techniques, laser flash method is the fastest measurement technique since the measurement time is in several microseconds, which is much shorter than THW measurement time in 2 to 8s [5]. Nevertheless, THW and TPS have longer measured time compare to LF, but their measurement time is considered fast and natural convection can be avoided by select measurement time range which without significant deviation from linearity of the graph. Furthermore, thermal comparator is also another measurement technique with fast response as this measurement technique can determine thermal conductivity of nanofluids just by contacting on nanofluids surface with a probe at an instant rate. In contrast, steady-state parallel method is relatively slow compared to other measuring technique due to the sample used in this technique is large, hence, it is required sufficiently amount of time to heat up the sample.

4. Conclusion

A brief review of different techniques for the measurement of thermal conductivity of nanofluids available in the literature has been made in this paper. The review shows that the transient hot-wire technique is the most frequently used thermal conductivity measurement technique of nanofluids due to the good reputation of THW. From this review activity a few key findings may be pointed out.

 Thermal conductivity of nanofluids could be influenced by various parameters such as volume fraction, temperature, material type of nanoparticles, pH value, stability of nanofluids and etc. However, most of the researchers focused on determining thermal conductivity of nanofluids for difference material type of nanoparticles and volume fraction.

 There is a high possibility of anomalous thermal conductivity enhancement of nanofluids is mainly due to inappropriate practice in the experiment. Proper procedures have to be formulated whereby assure the consistence measurement results.

 More benchmarking activity of a single type of nanofluids with various measuring techniques by strictly following standardizes procedure is preferable to validate anomalous thermal conductivity enhancement phenomenon of nanofluids.

 Although THW is the most recognizing measuring technique used to measure thermal conductivity of nanofluids. However, several conditions have to follow strictly when come into thermal conductivity measurement of nanofluids. These condition are using two wire arrangement
(eliminate the end effect), diameter of the wire less than 30mm (to mimic line heat source), insulated wire (avoid current leakage) and small temperature rise (avoid contamination of convection).

 Furthermore, two aspects have been discussed in the discussion where they are measuring time range and degree of disturbance. Based on these two aspects, it can be seen LF is the best methods since it can measure nanofluids at an instant rate without applied any disturbance on nanofluids. However, this method is still no a popular choice compared to THW. This may be due to the high maintenance cost and complex design. As a conclusion, the thermal conductivity enhancement mechanism of nanofluids is still a mystery, thus measurement technique has played a significant role to study the thermal behavior of nanofluids.

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