Experimental investigation of silver nano-fluid on heat pipe thermal performance

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Abstract

Nano-fluid is employed as the working medium for a conventional 211 μm wide × 217 μm deep grooved circular heat pipe. The nano-fluid used in this study is an aqueous solution of 35 nm diameter silver nano-particles. The experiment was performed to measure the temperature distribution and to compare the heat pipe thermal resistance using nano-fluid and DI-water. The tested nano-particle concentrations ranged from 1 mg/l to 100 mg/L. The condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constant-temperature bath maintained at 40 °C.

At a same charge volume, the measured nano-fluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of 30–60 W. The measured results also show that the thermal resistances of the heat pipe decrease as the silver nano-particle size and concentration increase.

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1. Introduction

Over the past decade, heat pipe use in electronic cooling applications has increased dramatically, primarily in notebook computers. In fact, virtually every notebook computer manufactured today uses at least one heat pipe assembly. Typically designed to carry less than 25 W of power, these parts are low in cost and are highly reliable. Heat pipe use in high-power (>150 W) cooling applications has been limited to custom applications requiring either low thermal resistance or with a severely restricted enclosure area. The cost of these larger diameter heat pipes is high due to a limited number of manufacturers and handmade assembly times.

With the progress in nanotechnology and thermal engineering, many efforts have been devoted to heat transfer enhancement. The usual enhancement techniques for heat transfer can barely meet the ever increasing demand of heat removal in high energy devices. However, traditional fluids have poor heat transfer properties compared to most solids. Therefore, Argonne National Laboratory has developed a new class of heat transfer fluids called “Nano-fluids”, which are engineered by suspending ultra-fine metallic or nonmetallic nanometer dimension particles in traditional fluids, such as water, engine oil, and ethylene glycol [1]. Some experimental investigations have revealed that nano-fluids have remarkably higher thermal conductivity and greater heat transfer characteristics than conventional pure fluids [1–7]. A theoretical model and an experimental setup are proposed to describe the heat transfer performance of nano-fluids flowing inside a tube. The experimental results illustrate that the thermal conductivity of nano-fluids remarkably increases as the volume fraction of ultra-fine particles increases [8].

In 2001, a nano-fluid consisting of copper nano-particles dispersed in ethylene glycol presented a much higher
effective thermal conductivity than either pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nano-particles [9]. The convective heat transfer feature and flow performance of Cu–water nano-fluids in a tube were experimentally investigated by Xuan and Li [10]. Sarit et al. investigated the increase in thermal conductivity with temperature for nano-fluids with water as the base fluid and Al2O3 or CuO particles as suspension material. The results indicated an increase in enhancement characteristics with temperature, which makes the nano-fluids even more attractive for applications with high energy density than usual room temperature measurements reported earlier [11]. You et al. performed boiling experiments, varying the conditions of fluids. The measured pool boiling curves for nano-fluids saturated at 60 °C demonstrated that the critical heat flux increases dramatically (~200% increase) compared to pure water [12].

In 2004, some researchers investigated the thermal performance of gold nano-fluids in meshed heat pipes. The circular meshed heat pipe had a length of 170 mm and an outer diameter of 6 mm. The heat pipe thermal resistance ranged from 0.17 to 0.215 °C/W. The measured results showed that the thermal resistance of the heat pipes with nano-fluids was lower than that of pipes containing pure water [13]. Recently, we demonstrated that a nano-fluid consisting of silver nano-particles in DI-water enhanced heated pipe thermal performance [14,15]. Similar experiments were observed in another recent study by Park et al. [16]. Their result also showed that silver nano-fluid heat pipe thermal performance was higher than that for a conventional heat pipe. The present study aims at assessing the effect of silver nano-fluid on grooved heat pipe. The result will be compared with 10 nm silver nano-particles dispersed in DI-water [15].

2. Experimental setup and procedure

2.1. Experimental setup

The nano-particles used in these experiments were silver particles 35 nm in size. The base working fluid was pure water. Silver (Ag) nano-fluids were prepared using a two-step method. Ag nano-particles were prepared first. They were produced using a catalytic chemical vapor deposition method (NANOHUBS TECHNOLOGY CO., LTD.). The silver nano-particles were then added to pure water. No surfactant was used in the Ag-nano-fluid suspensions. The mixture was prepared using an ultrasonic homogenizer. Nano-fluid concentrations of 1 mg/l, 10 mg/l, 50 mg/l, and 100 mg/l (ppm) were used in this study. Fig. 1 shows a TEM image of the Ag nano-particles.

An experimental system was set up to measure the thermal resistance of circular heat pipes (Fig. 2). The outer diameter and length of the heat pipes used in these experiments were 6 mm and 200 mm, respectively. The heat pipe contained 211 μm wide × 217 μm deep grooves.

The experimental system was composed of a cooling system, a test section, a power supply (CT605D) with an uncertainty of ±0.5%, a measurement system, and a data acquisition system (Spartan-L). A PC was used to monitor, log, and process the experimental data. The cooling system included a constant-temperature thermal bath and a cooling chamber. The condenser section of the flat heat pipe was inserted horizontally into the cooling chamber. The coolant circulated through the cooling chamber, where heat was removed from the condenser section by forced convection, and then to the constant-temperature bath. The constant-temperature bath was set to the required temperature and held at a constant-temperature through the tests. The temperature variation in the cooling fluid was maintained within 40 °C, and the operating temperature was varied over a range of 40–45 °C, with an uncertainty of ±0.1 °C. The power supply and measurement system utilized an electrical resistance heater powered by a DC power supplier. The electrical heater with a diameter of 10 mm was attached to one side of the evaporator section with thermal grease (SHIN ETSU X-23-7762) to reduce the contact thermal resistance between the heater and the heat pipe surface.

2.1.1. Test procedure

The power supply was then turned on and the power incremented. At this point in the tests, approximately 20–30 min was required to reach a steady state. Once the steady-state condition had been reached, the temperature distribution along the heat pipe was measured and recorded, along with the other experimental parameters. The power input was then increased incrementally, and the process repeated until dryout occurred as determined by rapid spikes in the evaporator thermal couple farthest from the condenser. Once dryout was reached, the temperature difference between the evaporator and condenser rap-
idly increased. The power input at this point was assumed to be the maximum heat transport capacity of the heat pipe at this power level and operating temperature, which is defined as the adiabatic vapor temperature.

The local heat pipe temperature was measured using five isolated Omega type-T thermocouples. Two thermocouples were attached to the evaporator; one was attached to the adiabatic section; and the others were attached to the condenser section. All thermocouples were calibrated against a quartz thermometer. The uncertainty in temperature measurements was ±0.1 °C.

Two heater bars (maximum 120 W) were used as a heat source in the heating section. Thus, the heating load \( (Q) \) and temperature difference \( (\Delta T) \) were measured, and the thermal resistance \( (R) \) was calculated using the equation \( R = \Delta T/Q \).

3. Results and discussion

3.1. Effect of the nano-fluid concentration

Figs. 3 [11] and 4 show the wall temperature distribution according to a heat pipe of 200 mm axial length with a diameter of 6 mm under water-cooling. As shown in Fig. 3(a), the wall temperature distributions of the heat pipe containing pure water were 41.06 °C, 40.96 °C, 40.92 °C, 40.89 °C, and 40.81 °C, respectively. After adding a small amount of silver nano-particles in the pure water, the heat pipe wall temperature became lower than that of pipes filled with pure water; from 40.56 °C to 40.37 °C (1 ppm). As more nano-particles became dispersed in the working fluid, the heat pipe wall temperature increase became smaller than that for a pure water filled heat pipe under various heat loads.

However, a continuing decrease in heat pipe wall temperature was not observed at concentrations higher than 50 ppm. Therefore, the 50 ppm nano-fluid is the lowest heat pipe increase in wall temperature.

3.2. Effect of the nano-particle size

To emphasize the particle size effect, the thermal resistance of the grooved heat pipe, filled with 10 nm and 35 nm silver nano-particles dispersed in DI-water, are shown in Fig. 5. The thermal resistances of a heat pipe containing pure water were 0.0052 °C/W, 0.0042 °C/W,
0.0038 °C/W, and 0.0036 °C/W, respectively. As Fig. 5(a) shows, the thermal resistance of a heat pipe containing 10 nm nano-particles was 52% lower than that using DI-water at 50 W. Fig. 5(b) shows the thermal resistance of a heat pipe containing 35 nm nano-particles was 81% lower than that using DI-water at 40 W. Moreover, the experimental results for 35 nm nano-particles in DI-water were obviously lower than that for 10 nm nano-particles in DI-water.
4. Conclusion

This paper discusses the thermal enhancement of heat pipe performance using silver nano-fluid as the working fluid. In the present case, DI-water diluted with 10 nm and 35 nm silver particles, inside a 211 µm wide x 217 µm deep grooved circular heat pipe was experimentally tested. The results of the performance test are as follows:

1. With greater silver nano-particles dispersed in working fluid, the increase in heat pipe wall temperature was smaller than that for a pure water filled heat pipe under various heat loads.
2. Comparing two nano-particle sizes with the thermal resistance value using DI-water, the maximum reduction was 50% (10 nm) and 80% (35 nm), respectively. Therefore, the thermal resistance of grooved heat pipe appears to be dependent on the size of the nano-particles.

The reason for heat pipe thermal enhancement can be explained as follows. Using the existing heat pipe and nano-fluid theories, particularly those related to the boiling limit, nano-particles can flatten the transverse temperature gradient of the fluid and reduce the boiling limit because of the increasing effective liquid conductance in heat pipes. Hence, the thermal resistance of a heat pipe is reduced for the same reason.

As a result, the higher thermal performances of nano-fluids indicates nano-fluid potential as a substitute for conventional pure water in grooved heat pipes. This finding makes nano-fluids more attractive as a cooling fluid for devices with high energy density. To reveal this phenomenon, further studies on nano-fluid behavior in heat pipes and the properties of nano-fluids must be performed.

Acknowledgments

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