Effect of Nanofluid Concentration on Heat Pipe Thermal Performance

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Abstract: - The thermal density of electronic parts and systems have been increased continuously as high speed and high density are required for them. The higher heat generation of the CPU of desktop PC than the Pentium-IV grade has been recently increased to more than 130W, and the available packaging space has been compacted. Therefore, in present study the nanofluid is employed as working medium for conventional 211 µm wide grooved circular heat pipe. The nanofluid used in the present case is an aqueous solution of various-solution sliver (Ag) nanoparticles. The average diameters of Ag nanoparticles is 10 nm. The experiment was performed to measure and compare thermal resistance of pure water and nanofluid filled heat pipes. At the same charge volume of 0.51mL, test result showed the average decrease of 28%-44% in thermal resistance of heat pipe with nanofluid as compared with pure water. As a result, the higher thermal performances of the nanofluid have proved its potential as substitute for conventional pure water in the grooved heat pipe.

Key-Words: - Nanofluid, heat pipe, thermal resistance, nanoparticles.

1. Introduction

Over the past decade, the use of heat pipes 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 used to carry less than 25 W of power, these parts are low in cost and highly reliable. Use of heat pipes in high-power (>150 W) cooling applications has been limited to custom applications requiring either low thermal resistance or having a severely restricted enclosure area. The cost of these larger diameter heat pipes was high due to a limited number of manufacturers and handmade assembly times.

With progresses of nanotechnology and thermal engineering, many efforts have been devoted to heat transfer enhancement. The usual enhancement techniques for heat transfer can hardly meet the challenge of ever increasing demand of heat removal in process of high energy devices. However, traditional fluids have poor heat transfer properties compared to most solid. Therefore, Argonne National Laboratory has developed the concept of a new class of heat transfer fluids called “Nanofluids,” which are engineered by suspending ultrafine metallic or nonmetallic particles of nanometer dimensions in traditional fluids such as water, engine oil, ethylene glycol (Choi, 1995). Some experimental investigations have revealed that the nanofluids have remarkably higher thermal conductivities and greater heat transfer characteristic than those of conventional pure fluids [1-6]. A theoretical model and an experimental are proposed to describe heat transfer performance of nanofluid flowing in a tube, the experimental results illustrate that the thermal conductivity of nanofluids remarkably increases with the volume fraction of ultra-fine particles [7].

In 2001, nanofluid consisting of copper nanoparticles dispersed in ethylene glycol has a much higher effective thermal conductivity than either pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nanoparticles [8]. The convective heat transfer feature and flow performance of Cu-water nanofluids in a tube have experimentally been investigated by Xuan and Li [9]. Sarit et al. go detailed into
investigating the increase of thermal conductivity with temperature for nanofluid with water as base fluid and particles of Al₂O₃ or CuO as suspension material, and the results indicated an increase of enhancement characteristics with temperature, which makes the nanofluids even more attractive for applications with high energy density than usual room temperature measurements reported earlier [10]. You and co-workers performed boiling experiments, varying conditions of fluids. The measured pool boiling curves of nanofluids saturated at 60°C have demonstrated that the critical heat flux increases dramatically (~200% increase) compared to pure water case [11].

In 2004, some researchers investigated gold nanofluid on meshed heat pipe thermal performance. The circular meshed heat pipe has a length 170 mm and an outer diameter of 6 mm. The thermal resistance of heat pipe ranges form 0.17 to 0.215 °C/W. The measured results show that the thermal resistance of the heat pipes with nanofluids is lower than with pure water [12].

2. Experimental Procedure

The nanoparticle used is silver particles of 10 nm in sizes. The base working fluid used is pure water. The test nanofluid was obtained by dispersing the nanoparticles (NANOHUBS TECHNOLOGY CO., LTD.) in pure water. The nanofluid concentration of 1 mg/l, 5 mg/l, 10 mg/l, and 50 mg/l, 100 mg/l (ppm) were used in the study. Figure 1 showed a TEM image of Ag nanoparticles with an average diameter of 10 nm.

In the experiment, the outer diameter and length of the heat pipe are 6 mm and 200 mm, respectively (Asia Vital Components CO., LTD). The heat pipe contained 211 μm wide grooves. An experimental system was set up to measure the wall temperature of circular heat pipes (Figure 2).
The experimental system was composed of a cooling system, the test section, a power supply and measurement system, and a data acquisition system (IMC Spartan-L). A PC was used to monitor and process the experimental data. The cooling system included a constant-temperature thermal reservoir and a cooling chamber. The condenser section of the 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 a constant-temperature reservoir. The constant-temperature reservoir was set to the required temperature and held at a constant temperature through the tests. The temperature variation of the cooling fluid was held to within 40°C.

The local temperature on the heat pipe was measured by five isolated type-T thermocouples. Two thermocouples were attached to the evaporator; one was attached to the adiabatic section, 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.

The power supply was turned on and the power incremented. At this point in the tests, it took approximately 15 to 20 minutes to reach 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 rapidly 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.

Two heater bars (maximum 120 W) were used as a heat source in the heating section. Thus, the heating load \( Q \) and temperature difference \( dT = T_{\text{evaporator}} - T_{\text{condenser}} \) were measured, and the thermal resistance \( R \) was calculated by the equation, \( R = dT / Q \). For present study, the heat pipe was horizontally fixed during measurement.

3. Analysis

Although heat pipes are very efficient heat transfer devices, they are subject to a number of heat transfer limitations. There are various parameters that put limitations and constraints on the steady and transient operation of heat pipes. These limitations determine the maximum heat transfer rate a particular heat pipe can achieve under certain working conditions. For high heat flux heat pipes operating in a low to moderate temperature range, the capillary and boiling limits are commonly the dominant factors that govern the operation of heat pipes. The calculation of the operational limitations for heat pipes can be found as follows.

**Capillary Limit.** For a given capillary wick structure and working fluid combination, the pumping ability of the capillary structure to provide the circulation for a given working medium is limited. This limit is usually called the capillary or hydrodynamic limit. In order to maintain the continuity of the interfacial evaporation, the capillary pressure head must be greater than or equal to the sum of pressure losses along the vapor-liquid path. The pressure balance can be expressed as \[ \Delta P_{\text{exp, sum}} \geq \Delta P_i + \Delta P_v + P_{v,\delta} + P_{v,\delta} + \Delta P_g \] (1)

**Boiling Limit.** Nucleation within the capillary wick is undesirable for wicked heat pipe operation since the bubbles can obstruct the liquid circulation and cause hot spots on the
heated wall. If the boiling is severe it dries out the pipe wall, which is defined as the boiling limit. However, under a moderate heat flux, low intensity stable boiling is possible without causing dryout. It should be noted that the boiling limitation is a radial heat flux limitation as compared to an axial heat flux limitation for the other heat pipe limits.

The boiling limit is directly related to bubble formation in the liquid. In order that a bubble can exist and grow in a liquid, a certain liquid superheat is required. On the other hand, in order that a bubble can exist and grow in a superheated liquid, its size must be larger than a critical value. The relation for the critical size of a bubble or nucleus under a certain liquid superheat and physical properties can be expressed as [13]

\[ R_n \geq \frac{2\sigma \Delta \rho_{v,\text{sat}}}{h_f \rho_{v,\text{sat}} \Delta T} \]  

If the nucleus is smaller than the critical size, it is unstable and the nucleus will disappear after a short period of time. In 2004, C.Y. Tsai et al. [9] explained the reason for reducing the thermal resistance of heat pipe, revealing that the nucleation size of vapor bubble is smaller for fluid with suspended nanoparticles than without them.

### 4. Results and Discuss

Figure 3 shows the distribution of wall temperature according to the axial length of 200mm heat pipes having the diameter of 6mm under the water-cooling. As Figure 3(a) shown by findings, the distribution of wall temperature of heat pipe containing pure water were 41.06°C, 40.96°C, 40.92°C, 40.89°C, 40.81°C, respectively. After adding extremely small amount of silver nanoparticles in the pure water illustrated a sizable decrease in the wall temperature of heat pipe; from 40.72°C to 40.58°C (5 ppm).

It also shows the more the nanoparticles were dispersed in working fluid, the smaller the rise in wall temperature of heat pipe than pure was filled in heat pipe under various heat load. The 50 ppm nanofluid is the lowest rising wall temperature of heat pipe.
Fig. 3 Measured values of wall temperature of heat pipe with pure water and nanofluid prepared by different concentration.

Fig. 4 Wall temperature versus concentration of nanofluid at different heat load.

Figure 4 shows the wall temperature under various concentrations of nanofluid and input power. It can be seen that the wall temperature of heat pipe containing pure water is the highest than nanofluid under various heat load.
Figure 5 illustrates the thermal resistance of grooved heat pipe containing silver nanofluid and pure water as working fluid. The figure shows the thermal resistance of heat pipes were 0.0036°C/W, 0.0029°C/W, 0.0023°C/W, 0.0022°C/W, 0.0021°C/W, 0.002°C/W, respectively. It can be seen that by increasing concentration of nanofluid the thermal performance of heat pipe can be decreased.

The effect of adding silver nanoparticles on the thermal performance of the grooved heat pipe is more evident if the data are expressed as a plot of $R_{water} - R_{nanofluid}/R_{water}$ versus nanofluid concentration, as shown in Figure 6. This graph shows the reducing rate of thermal resistance were 0.28, 0.38, 0.4, 0.42, 0.44 under different concentration, respectively. However, the continuing dramatically increasing of thermal performance was not observed at the highest concentration. As a result, there may exist an optimum concentration for a given grooved heat pipe at a specific charge volume.

Figure 6 Reducing rate of thermal resistance at different concentrations.

5. Conclusion

This paper deals with the thermal enhancement of the heat pipe performance, using silver-nanofluid as the working fluid. A nanofluid is an innovative heat pipe working fluid with metal nanoparticles dispersed on it. In present case, the pure water with diluted 10 nm silver particles, inside 211 microns wide grooved circular heat pipes, was experimentally tested, showing that the thermal performance of the heat pipe was considerably increased.

The major reason for increasing the thermal performance of heat pipe by using nanofluid can be explained as follows. The critical heat flux [11] and convective heat coefficient [14] of nanofluid is higher than pure water. Therefore, it is expected that the thermal performance of heat pipe will be enhanced. As a result, the higher thermal performances of the nanofluid have proved its potential as substitute for conventional pure water in the grooved heat pipe.
Nomenclature

\( h_{fg} \) = Latent heat of vaporization, J/kg

\( \Delta P_{\text{cap} \text{max}} \) = The maximum capillary head

\( \Delta P_g \) = The pressure drop in the liquid due to the effect of the gravitational force in the direction of the heat pipe, Pa

\( \Delta P_l \) = The liquid pressure drop, Pa

\( \Delta P_v \) = The vapor pressure drop, Pa

\( \Delta P_{evapor} \) = The pressure drop due to the condensation at liquid-vapor interface, Pa

\( \Delta P_{evapor} \) = The pressure drop due to the evaporation at liquid and vapor interface, Pa

\( Q \) = Heat load, W

\( R \) = Thermal resistance, °C/W

\( R_{water} \) = Thermal resistance of heat pipe containing pure water, °C/W

\( R_{water} \) = Thermal resistance of heat pipe containing nanofluid, °C/W

\( R_b \) = Radius of vapor bubble, m

\( T_{\text{condenser}} \) = Temperature of condenser section, °C

\( T_{\text{evaporator}} \) = Temperature of evaporator section

\( T_{sat} \) = Saturation temperature, °C

Greek Alphabet

\( \sigma \) = Liquid-vapor interface surface tension, N/m

\( \delta \) = Liquid film thickness, m

\( \rho_{sat} \) = Density of saturated vapor, kg/m³

Subscripts

b = bubble
cap = capillary
e = evaporator or evaporation
g = gravity
l = liquid phase
max = maximum
sat = saturation
v = vapor phase

References:


