

# Performance Test of Silver Nano-fluid Filled Screen-Wick Heat Pipes

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## Abstract

This study reports on preliminary experimental results on using silver (Ag) nanofluids to enhance the screen-wick heat pipe thermal performance. The nano-particles used in these experiments were Ag particles 35 nm in size. The base working fluid was pure-water. Ag nano-fluids were prepared using a two-step method. In the experiment, the outer diameter and length of the heat pipe are 6 mm and 200 mm, respectively. An experimental system was set up to measure the temperature distribution of heat pipes and calculate the thermal resistance by equation  $R = \Delta T / Q$ . At a same charge volume, there is a reduction in thermal resistance of heat pipe with nano-fluid as compared with DI water.

*Key Words:* heat pipe, nano-fluid, thermal resistance.

## 1. INTRODUCTION

Over the past decade, the electronic components produce more and more heat and the heat transfer by conduction is not sufficient anymore. One of the solutions is the use of heat pipes. Nowadays, we commonly find heat pipes in notebook computers, game consoles, and even integrated into normal PC CPU coolers.

With progresses of micro-electronics and nanotechnology, the computational speed of the operating systems creates highly concentrated heat flux. Heat pipes have been widely used in many electronic cooling systems because of their high thermal conductivity with small temperature difference and no electrical power supply required. However, traditional working fluids have poor heat transfer properties compared to most solid. In 1995, 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. Some experimental investigations have revealed that the nanofluids have remarkably higher thermal conductivities and greater heat transfer characteristic than those of conventional pure fluids [1-7].

In 2004, some researchers investigated the thermal performance of gold nano-fluids in meshed heat pipes. The circular meshed heat pipe had a length 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 show that the thermal resistance of the heat pipes with nano-fluids was lower than

pipes containing pure water [8]. Recently, we demonstrated that a nano-fluid consisting of silver nano-particles in DI-water enhanced grooved heat pipe thermal performance [9-10]. Similar experiments were observed in another recent study by Park et al. [11]. 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 the effect of silver nano-fluid on screen-wick heat pipe. The result will be compared with DI-water filled heat pipe.

## 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. Ag nano-particles 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 created using an ultrasonic homogenizer. Nano-fluid concentrations of 15 mg/l and 50 mg/l (ppm) were used in this study. Figure.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 (Figure.2). The outer diameter and length of the heat pipes used in these experiments were 6 mm and 200 mm, respectively.

The experimental system was composed of a cooling system, the test section, a power supply (CT605D) with an uncertainty of 0.5%, and 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 a 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 held to within 40 °C, and the operating temperature was varied over a range of 40 °C to 45 °C within an uncertainty of  $\pm 0.1$  °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.

## 2-2 Test procedure

The power supply was then turned on and the power incremented. At this point in the tests, approximately 20 to 30 minutes was required 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.

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, the others were attached to the condenser section. All thermocouples were calibrated against a quartz thermometer. The uncertainty in temperature measurements was  $\pm 0.1$  °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

Figure 3 shows the distribution of wall temperature according to the axial length of 200 mm heat pipes having the diameter of 6 mm at various input power. As Figure 3(d) shown by findings, the distribution of wall temperature of heat pipe containing pure water were 52.80°C, 50.29°C, 49.29°C, 49.14°C, 49.01°C, respectively. After adding a small amount of silver nano-particles in the pure water, the average temperature of evaporator section (15 mm) were 51.34°C (15 PPM) and 50.00°C (50 PPM). It indicates that the Ag-nano-fluid can decrease the temperature of evaporator section. A Similar phenomenon was observed in another recent study by T. Israeli et al. [11].

Figure 4 and Figure 5 show the average temperature difference and thermal resistance of heat pipes in different heat load and concentrations. In Fig. 4, the temperature difference of heat pipes containing pure water were 0.80°C, 1.20°C, 2.10°C, 2.50°C, respectively. It can be seen that the temperature difference of heat pipe containing pure water is the higher than using nanofluid under various heat load. In Fig. 5, the thermal resistance of heat pipe increases with increases in heat load. It can be also seen that the thermal resistance of heat pipes containing pure water is the higher than using nanofluid under various heat load. Moreover, the experimental results for 15 PPM Ag-nanofluid thermal performance were lower than 50 PPM.

## 4. Analysis

Although heat pipes are very efficient heat transfer devices, they are subject to a number of heat transfer limitations. We try to perform some preliminary calculations so as to gain a sense of the magnitude of improvement in the thermal performance of heat pipes using nanofluids. A simple one-dimensional thermal network model for metal screen wick heat pipe is shown in Figure 6 [13]. Several authors have indicated that only three resistances, the combined effect ( $R_3+R_4$ ), ( $R_6+R_7$ ) and  $R_{10}$  are predominant. Further,  $R_4$  and  $R_6$  are relatively small since boiling and condensation are efficient heat transfer processes. Hence only,  $R_3$ ,  $R_7$  and  $R_{10}$  need to be considered. Under this assumption, we have the following model for heat pipe overall resistance:

$$\frac{1}{R_{HeatPipe}} = \frac{1}{R_{Evaporatorwick} + R_{Condensewick}} + \frac{1}{R_{wall(X)}} \quad (1)$$

According to the heat pipe theory, the thermal resistance of screen wick heat pipes,  $R_3$  and  $R_7$  to be estimated as:

$$R_{wick} = \frac{\ln(d_o/d_i)}{2\pi L k_{eff,wick}} \quad (2)$$

where  $k_l$  and  $k_s$  are the thermal conductivities of the working fluid and the solid material of the wick respectively, and  $\phi$  is the wick's porosity.

The effective thermal conductivity of the wick ( $k_{eff,wick}$ ) is a function of the wick geometry, material and the working liquid or, alternately, the thermal conductivity of both substances and the porosity of the wick. A conventional equation for calculating the effective thermal coefficient for metal screen wicks is given by [13]:

$$k_{eff,wick} = \frac{k_l[(k_l + k_s) - (1 - \phi)(k_l - k_s)]}{[(k_l + k_s) + (1 - \phi)(k_l - k_s)]} \quad (3)$$

Since the adding nanoparticles would increase the thermal conductivity of the working fluid, the decrease in heat pipe wick's resistance filled nanofluids can be estimated using the equation (2) and equation (3). Therefore, the reduction in overall heat pipe thermal resistance could be prediction.

## 5. Conclusion

This paper presents preliminary results on the thermal enhancement of screen-wick heat pipes using nano-fluids. In the present case, pure water diluted with 35 nm silver nano-particles, screen-wick circular heat pipe was experimentally tested. The temperature difference and the thermal resistance of the heat pipes with silver nano-particle solution were lower than that with pure water. In addition, the heat pipe performance with 15 PPM Ag nano-fluid was higher than 50 PPM. 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 effective thermal conductivity of wick structure, and nano-particles can flatten the transverse temperature gradient of the fluid and reduce the wick's thermal resistance because of increasing effective liquid conductance in heat pipes. Hence, the thermal resistance of a heat pipe is reduced for the same reason.

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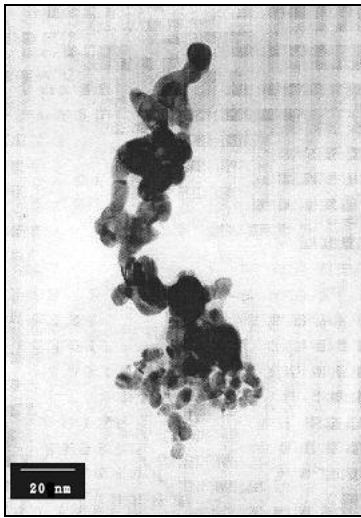


Figure 1. TEM micrograph of Ag nano-particles (35 nm)

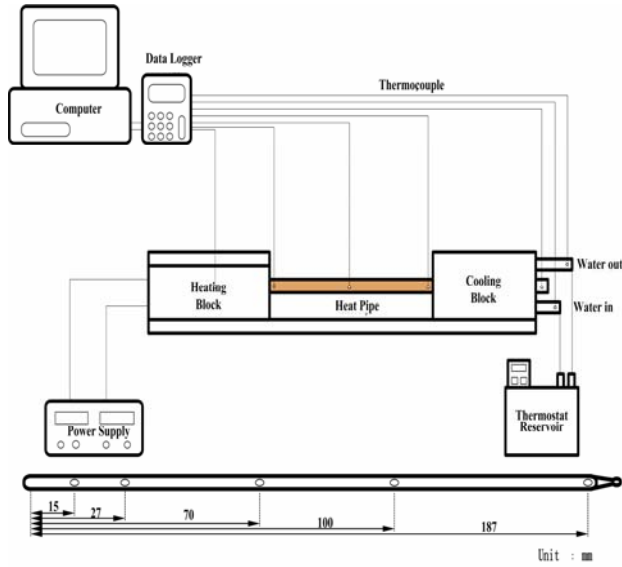
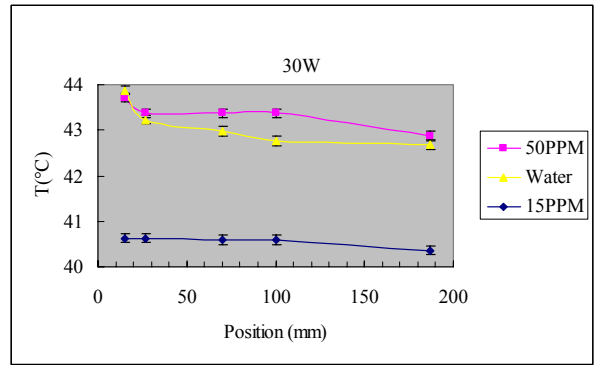
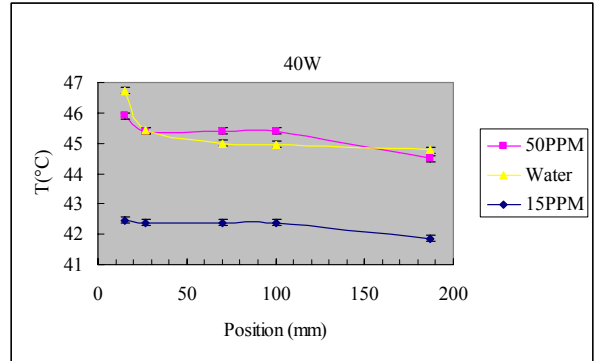


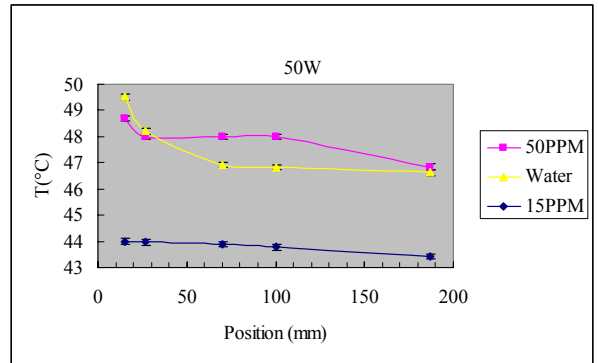
Figure 2. Schematic of the experimental setup and thermocouple distributions on the tested heat pipe.



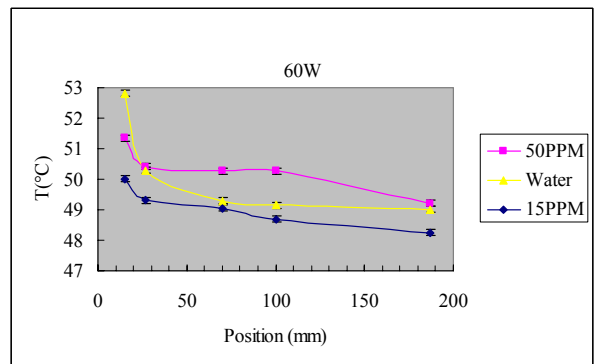
(a)



(b)



(c)



(d)

Figure 3. Average temperature of heat pipes distribution in different heat load and concentrations.

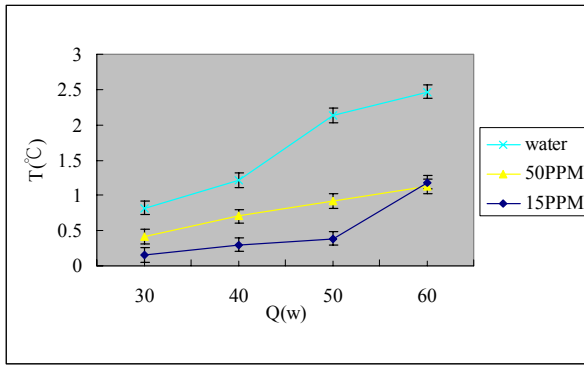


Figure 4. Average temperature difference of heat pipe distribution in different heat load and distribution in different heat load and concentrations.

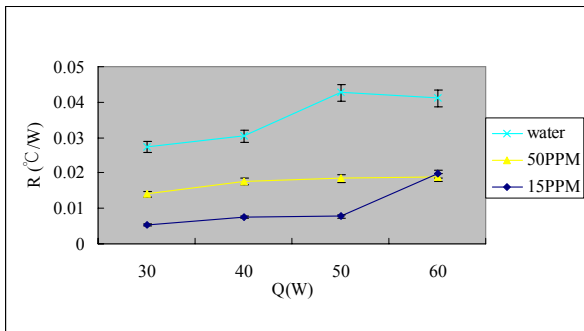


Figure 5. Effect of various fluids on the thermal resistance of heat pipe.

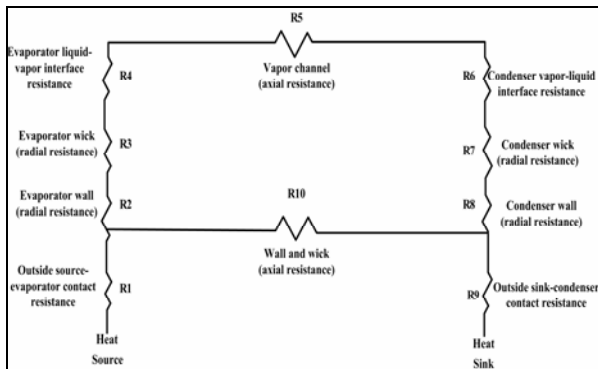


Figure 6. Simplified thermal resistance model of a heat pipe [13].