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INVESTIGATION ON THERMAL PERFORMANCE OF THE FLAT PLATE HEAT PIPE USING CFD ANALYSIS

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Abstract- Flat Plate Heat Pipe (FPHP) is the effective device due to its heat transferring nature, light weight and high effective thermal conductivity, flat plate heat pipes (FPHP) has been recognized as potential devices in this challenging part of thermal control of high density electronic devices. This present paper is a report of such an experiment which is a development of smaller size flat plate heat pipes (60x60x30mm), made up of magnesium as body material, sintered copper as wick structure and the working fluid used is a nano fluid prepared from Copper Oxide (CuO) nanoparticles dissolved in De-ionized water. Elaborative experiments were conducted to ascertain the thermal performance of the fabricated heat pipe and detailed analysis is discussed from the outcomes of the experiments. The FPHP charged with the CuO nanofluid has been tested for thermal performance and found to be improved with the rise in temperature. The condenser section has been tested with natural convection. The steady state experiments are conducted under transient condition by varying the heat input from 0 to 100 Watts continuously. The thermal performance results have been analyzed using Computational Fluid Dynamics (CFD) and found to be in good agreement with the previous studies done under the transient and steady state conditions.

Keywords – *Heat* pipes, FPHP, Thermal performance, Natural convection, Nanofluid

I.Introduction

Flat Plate heat pipes are much like traditional cylindrical heat pipes. The only real difference between the two is in the geometrical shape. Due to the different surface area geometry, flat plate heat pipes also have flow and structural design considerations different from those of cylindrical heat pipes (Shah & Sekulic 2003). Flat plate heat pipes are used to cool and flatten temperatures of semiconductor or transistor packages assembled in arrays on the top of the heat pipe. This is due to their heat transferring nature, light weight and high effective thermal conductivity. Flat plate heat pipes (FPHP) are recognized as potential devices in this challenging part of thermal control of high density electronic devices (Xuan et al. 2004). The wick provides a means for the flow of liquid from the condenser to the evaporator section of the heat pipe. It also provides surface pores required at the liquid–vapor interface for development of the required capillary pressure. The wick structure also has an impact on the radial temperature drop at the evaporator end between the inner heat pipe surface and the liquid–vapor surface. Thus, an effective wick requires large internal pores in a direction normal to the heat flow path. This minimizes liquid flow resistance. In addition, small surface pores are required for the development of high capillary pressure and a highly conductive heat flow path for minimization of the radial surface to liquid–vapor surface temperature drop. Design of a flat plate heat pipe is a complicated task involving major concept of heat transfer and temperature distribution as well as the operating limits of the heat pipes. So it is essential for an engineer to have a thorough knowledge of heat transfer mechanisms. The operation of a heat pipe involves all types of heat transfer mechanisms like conduction, convection, radiation, heat transfer with phase change i.e., boiling heat transfer, condensation heat transfer and heat transfer through extended surfaces. The basic data required for the design of a heat pipe is the heat flux to be handled. The design of a flat heat pipe is quite complicated. The dimensions of the heat pipe and the materials used for construction are usually selected on the basis of the application. The designed heat pipe needs to be checked for various limitations. The heat transport capacity of a heat pipe is limited by different mechanisms which depend on the geometry, wick structure, vapour channel space, working fluid and operating temperature. The maximum heat load permitted by these phenomena is known as the limit (or limitation) of heat pipe. The various limits of FPHP are capillary limit, viscous limit, entrainment limit, boiling limit, sonic limit and thermal resistance limit.

II.Design of FPHP

To Design a FPHP, considerations like choice of the container, working fluid level, geometric design and structure of wick layers are made. Container is made up of magnesium which encases the working fluid. Magnesium is an abundant material which is stronger than aluminium but lighter in weight. Magnesium has shown promise as a

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lighter-weight alternative to the aluminum alloys now used to make the main structural components of axially grooved heat pipes that contain ammonia as the working fluid. Lightweight Heat Pipes were made from Magnesium (Rosenfeld et al. 2010). Magnesium heat-pipe structures can be fabricated by conventional processes that include extrusion, machining, welding, and bending. The thermal performances of magnesium heat pipes are the same as those of equal-sized aluminum heat pipes. However, by virtue of the lower mass density of magnesium, the magnesium heat pipes weigh 35 percent less. Conceived for use aboard spacecraft, magnesium heat pipes could also be attractive as heat-transfer devices in terrestrial applications in which minimization of weight. It strongly bounds to avoid leak in outside environment and also enables heat transfer to take place from and into the working fluid by maintaining the pressure difference across the surrounded walls.

The Physical dimensions of the flat plate heat pipe designed and fabricated by using operating limitations are shown in Table 1.

Table 1 Physical Dimension Of Flat Plate Heat Pipe

Parameters	Values
Length	60mm
Width	60mm
Height	30mm
Thickness of Wall	2mm
Thickness of Wick	0.2mm

III. Selection Of Nanofluids

The reason behind the selection of nanofluids is to use them as thermofluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipments. Nanofluids help in conserving heat energy and heat exchanger material. The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density (Xuan & Roetzel 2000). The thermo physical properties of nanofluids also depend on operating temperature of nanofluids. Hence, the accurate measurement of temperature dependent properties of nanofluids is essential. Thermo physical properties of nanofluids are pre requisites for estimation of heat transfer coefficient and the Nusselt number (Bang & Chang 2005).

IV. Synthesis of CuO NanoFluids

Copper oxide nano powders were synthesized by chemical reduction method in which Copper nitrate trihydrate was used as a precursor and sodium hydroxide (NaOH) as a reducing agent (Khanna et al. 2007). 0.05, 0.1 and 0.2M copper nitrate trihydrate was dissolved in 100 ml water and 0.75M sodium hydroxide was also dissolved in 20 ml water by stirring. Sodium hydroxide solution was added drop by drop to copper nitrate solution. The black colour precipitate was obtained after complete reduction of copper nitrate to copper oxide. Precipitate was filtered and washed twice with water and twice with methanol and dried in vacuum. Black colour CuO nano powder was collected.

For the preparation of CuO nanofluids, 25 mg copper oxide nano powder was mixed with 50 mL of ethylene glycol/water base fluid as a volume media of 45:55 and stirring for 2 hours. For proper dispersion, the resulting solutions were kept on sonicator for 2 hours. A stable Nanofluid with uniform particle dispersion can be prepared by mixing nanoparticles in an acid treated base fluid (Hwang et al. 2008). But acid treated nanofluids may cause corrosion on the pipe wall material with prolonged usage of nanofluids. Hence acid treated base fluids are not preferred for preparation of Nanofluids even though formation of stable nanofluids is possible with such base fluids. Normally agglomeration of nanoparticles takes place when nanoparticles are suspended in the base fluid. The CuO nanofluids samples thus prepared are kept for observation and no particle settlement was observed at the bottom of the flask containing CuO nanofluids even after four hours.

V. Measurement Of Thermal Conductivity

Thermal conductivity of base fluids was recorded first before recording the thermal conductivity of CuO nanofluids (0.2%) at 25°C. The thermal conductivity enhancements in nanofluids dispersed in water was relatively low, and it may be due to some agglomeration or precursor's effects or nature of base fluids. The thermal conductivity enhancement value (%) of Ethylene Glycol/water medium was greater than the water medium. In overall, it was also clear that all nanofluids were showing more thermal conductivity enhancement over their base fluids as shown in Table 2.

Sample	Thermal conductivity (W/mK)	Enhancement in Thermal Conductivity (%)
Water	0.6108	-
CuO with water	0.8303	36

The values of thermal conductivity of water base fluid and ethylene glycol/ water base fluids were 0.6108W mK-1 and 0.4943 W mK^{-1} respectively. The thermal conductivity of Nanofluid dispersed in water medium was 0.8303 W mK^{-1} which showed 36% enhancements of thermal conductivities respectively over their base fluid.

VI. Thermal performance of FPHP

The fabricated flat plate heatpipe was experimented with CuO nanofluid with base fluid of water and ethylene glycol mixture. Experiments were conducted to ascertain the thermal performance of the heat pipe and detailed analysis is discussed from the outcomes of the experiments. Flat plate heat pipe is connected with the charging set up for filling working fluid along with pressure gauges and vacuum gauge to measure the pressure through which the temperature can be ascertained. The heater which is attached with the heat pipe at the bottom of the evaporator section is supplied with electrical energy from Wheatstone bridge where the voltage and current are controlled by the regulators.

T-type thermocouples are fitted in eight places viz., heater, both sides of the evaporator wall, vapor area at evaporator, vapor area at condenser, both side of the condenser wall and fins section at the condenser end as shown in Figure 1. All thermocouples have been connected to data acquisition system which is supported by PC section. Calibrations have been done for all eight thermocouples by using quartz thermometer.

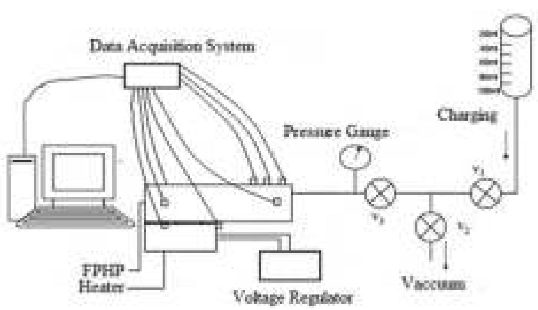

Figure 1. Arrangement Of Thermal Measurement Setup

The power input was varied from 20 W to 100 W with 20 W increments in each step and the data obtained were plotted as shown in Figure 2-6.

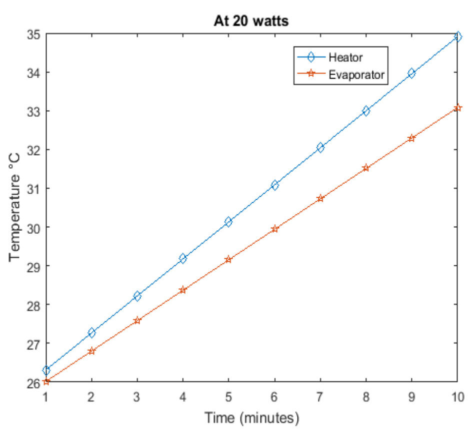

Figure 2. Heater Vs Evaporator at 20 Watts

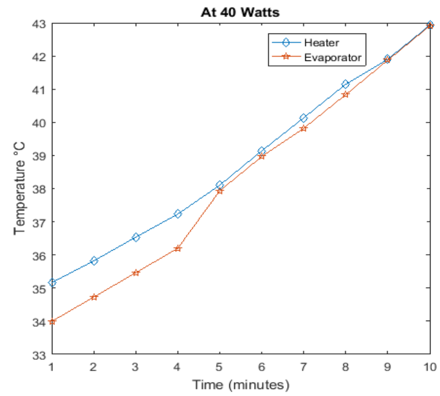

Figure 3. Heater Vs Evaporator at 40 Watts

This experiment was conducted in a transient state as the heat input was varied continuosly without allowing the steady state. This is aimed to find out the temperature difference handled by the flat plate heat pipe with the increasing temperatures of the heater.

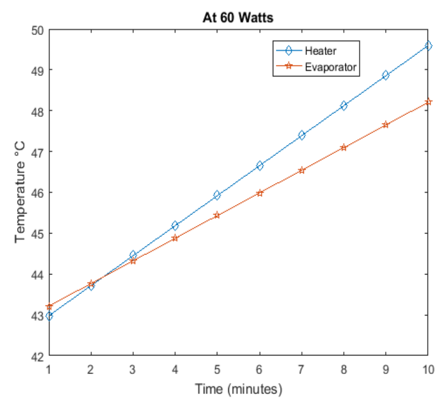

Figure 4 Heater Vs Evaporator at 60 Watts

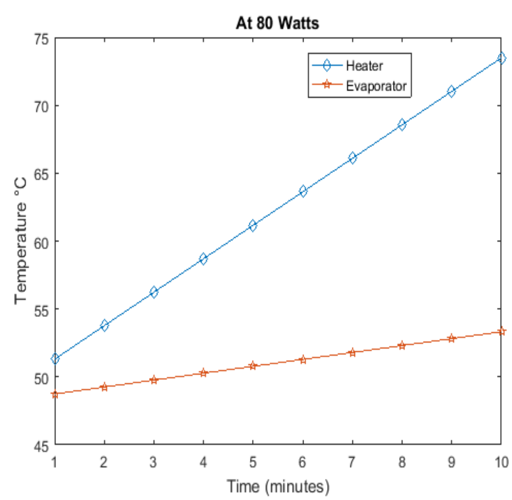

Figure 5 Heater Vs Evaporator at 80 Watts

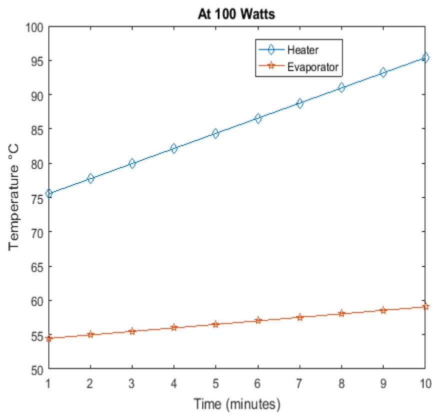

Figure 6 Heater Vs Evaporator at 100 Watts

The temperature of the flat plate heat pipe is increasing upto 40 Watts heat input and it shows that the entire body and structure of the heat pipe is getting heated up initially. On reaching about 43°C at 60 Watts heat input, the liquid filled in the heat pipe is started evaporating as the temperature of the evaporator reaches the saturation temperature of the liquid. The temperature of the heater is further allowed to increase with the increased heat input upto 100 Watts. The temperature difference between the heater and the evaporator is also continuously improving to 36°C when the heater reaches 95°C. So it is evident that the heat pipe is capable of handling higher heat inputs even after 100 Watts and higher temperatures.

The Overall thermal performance of the flat plate heat pipe is shown in Figure 7. When the heater reaches the temperature of 95°C, the evaporator maintains its temperature at 60°C. At this stage, the condenser temperature is 49°C and temperature at the fins is 40°C where the heat is transferred to the atmosphere. Hence the overall performance of the flat plate heat pipe in transient condition is found to be in good agreement with the previous studies conducted in transient conditions (Chen et al. 2014) and even the heat pipe attains the steady state condition.

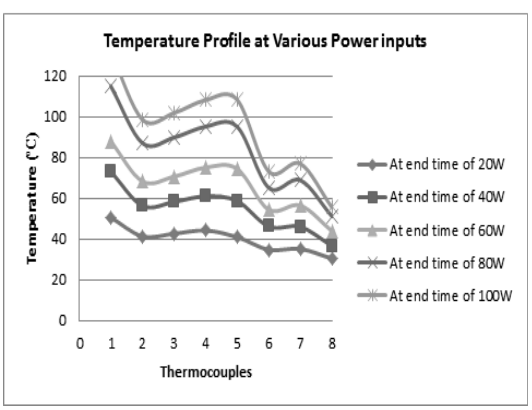

Figure 7 Temperature Profile at Various Power inputs

VII.CFD Analysis

The temperature profile along the heat pipe for different power inputs is shown in Figure 7. It is observed that the temperature is reduced from the heater to the evaporator due to the phase change of the working fluid and it increases slightly upto the wick structure due to the resistance offered by the wick structure. This temperature reduces further at the condenser section and again reduces near the condenser fins section due to the heat transfer to the atmosphere. The drop in temperature from heater to condenser fins section is increasing with rise in power input. The temperature profile shows better variation in each thermocouple along the length of the flat plate heat pipe. The experimental temperature distribution of the heat pipe has been compared with the results of CFD analysis which is shown in Figure 8.

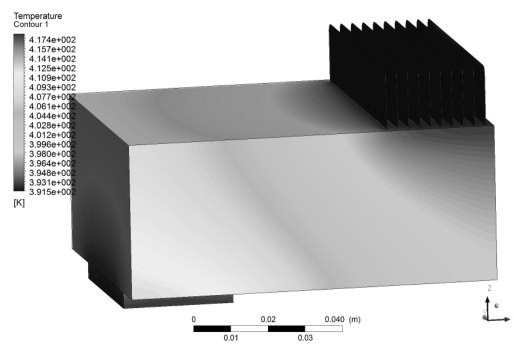

Figure 8 Overall Temperature Distributions Of The Heat Pipe

VIII.Conclusion

Though the previous research works were concentrated on the steady state experiments the present experiment is conducted under transient condition by varying the heat input from 0 to 100 Watts continuously. The recorded data with respected time were analyzed to evaluate the performance of the heat pipe at higher temperatures. The results have been analyzed and found to be in good agreement in terms of FPHP thermal performance. Comparison of experimental temperature distribution of the heat pipe with the results of CFD analysis is helpful to identify thermal variation across different places.

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