Effect of Filling Rate of Working Fluid on Thermal Performance of Flat Heat Pipe

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Abstract

This research is investigated effect of filling rate of working fluid on thermal performance flat heat pipe. The flat heat pipe (FHP) made a copper tube with an internal and external diameter of 5.4 mm and 6 mm, respectively. The wick structure made from copper pounder sintering. The copper tube is flatted of 3 mm after sintering, the porosity of wick was 50% ± 5%, and the wick thickness was 0.6 mm. In the experimental, the filling rates are 40%, 50% and 60% respectively. The FHPs were set to operate at horizontal heating mode. It was found that the filling rate at 60 %, heat pipe can transfer heat maximum is 40 W and the thermal resistant is 0.02 ^{o}C/W.

Keyword: Filling Rate, Thermal Performance, Flat Heat Pipe

1. Introduction

Recently, electronic cooling systems has become a critical technology in many products; underdevelopment of electronic product is small to response of user need in the marketplace. This is driven by rapid progress in advanced high power electronic packages when the traditional heat removal techniques such as air-cooled finned are not enough cooling. Thus, heat exchangers are needed to develop to high specifications for compactness reliability and performance. Therefore, the flat plate heat pipe has been identified as having potential in this challenging area of heat dissipation in electronic devices. The flat heat pipe functions in a substantially different manner as compared to the conventional tubular heat pipes, as it involves a more complex transport mechanism. These because thermal characteristics many applications such as cooling of high power semiconductor chips and cooling of electronic equipment. An experimental investigation of the thermal performance of a flat heat pipe by Vafai et al. [1].They are indicate the porous wick of the evaporator section creates the main thermal resistance resulting in the largest temperature drop, which consequently affects the performance of the heat pipe and were compared with the analytical. Analytical models for predicting the transient performance of a flat plate heat pipe for startup and shutdown operations are work by Wang and Vafai [2].

They are showed the model of transient temperature distributions and the thermal diffusivity, the thickness of the wall and the wick, and the heat input pattern affect the heat pipe time constants. They were found that the wicks create the main thermal resistance resulting in the largest temperature drop in the heat pipe. Tan et. al [3] study the effective heat transport length of a flat plate heat pipe with multiple heat sources that found. Minimum effective length is obtainable at the optimum heat source positions where the heat pipe capillary heat transport limit is the highest and its operational performance is the best. Hence, it is useful in thermal management of electronic systems as this approach helps to determine the optimum heat source positions on the heat pipe that allows the cooling of electronic components or system more effectively and efficiently. The analysis of an experimental investigation into determining the thermal performance of a flat plate heat pipe using infra red (IR) thermal imaging camera was study by Boukhanouf [4]. They found that the thermal spreading resistance of the flat plate heat pipe smaller than that of the solid copper block and flat plate heat pipe with a defect. A liquid and vapor flow model coupled to a thermal model is presented for a flat plate heat pipe with micro-grooves investigated by Monique Lallemand et al. [5]. This model allows the calculation of the liquid and vapor pressures and velocities, the meniscus curvature radius in the grooves and the temperature field in the heat pipe wall from the heat source to the heat sink. The meniscus curvature radius is introduced in the thermal model to take into account the heat transfer at the liquid–vapor interface. Experimental measurements of the meniscus curvature radius as well as temperature measurements along a grooved heat pipe are compared to the model results. Both comparisons show the good ability of the numerical model to predict the maximum heat transport capability and the temperature field in the heat pipe. The effects of the liquid–vapor interfacial shear stress, the contact angle, and the amount of liquid charge of a flat micro heat pipe with a rectangular grooved wick structure is study by KyuHyung Do et al [6] , They present model of the axial variations of the wall temperature and the evaporation and condensation rates are considered by solving the one-dimensional conduction equation for the wall and the augmented Young–Laplace equation. They found that the maximum heat transport rate of a micro heat pipe with a grooved wick structure is optimized with respect to the width and the height of the groove. The maximum heat transport rate for the optimum conditions is enhanced by approximately 20% compared to existing experimental results. Zhang Minget et al. [7] study effective of thermal spreader can achieve uniform heat flux distribution and thus enhance heat dissipation of heat sinks of flat plate heat pipe. Magnetic fluid is liquid and can be moved by the force of magnetic field. The magnetic fluid is suitable to be used as the working fluid of flat plate heat pipes which have a very small gap between evaporation and condensation surfaces. They prepared a disk-shaped wickless flat plate heat pipe, and the distance between evaporation and condensation surfaces is only 1 mm. Also they compared the experimental results between the performance of water and magnetic fluid as working fluids. The experiments were performed to investigate the effect of evaporation and condensation length on thermal performance of flat plate heat pipes (FPHP) is study by Shuang feng Wang [8]. In the experiments, the FPHP had heat transfer length of 255 mm and width of 25 mm, and pure water was used as the working fluid. The results show that comparing to vapor chamber, the FPHP could realize long-distance heat transfer; comparing to the traditional heat pipe, the FPHP has large area contact with heat sources; the thermal resistance decreased and the heat transfer limit increased with the increase of evaporation section length; the FPHP would dry out at a lower heating power with the increase of condensation section length, which indicated that the heat transfer limit decreased, but the evaporator temperature also decreased; when the condensation section length approached to evaporation section length, the FPHP had a better thermal performance.

From the above mentioned will be seen the effect of the filling rate of working of the flat pipe heat is studies not clear. Therefore, this research was interested to study the effect of the filling ratio of working fluid to affect the heat transfer performance of flat heat pipe.

2. Experimental Setup

The flat heat pipe (FHP) made a copper tube with an internal and external diameter of 5.4 mm and 6 mm, respectively, was used as the material in this experiment. The copper tube was sintering a layer of copper powder (the porosity of capillary was 50% ±5%), and the wick thickness was 0.6 mm. The sealing was welded by the argon arc welding technology. The vacuum was established by using a vacuum pump, and then the water is used working fluid and filled in the FHP (the filling rates was about 40%, 50% and 60% wick volume). A long strip FHP was successfully fabricated; the total length of FHP is 200 mm and is flatted 3 mm. The experimental apparatus of FHP is shown in Fig. 1. The operational orientation was horizontal heating mode, where the

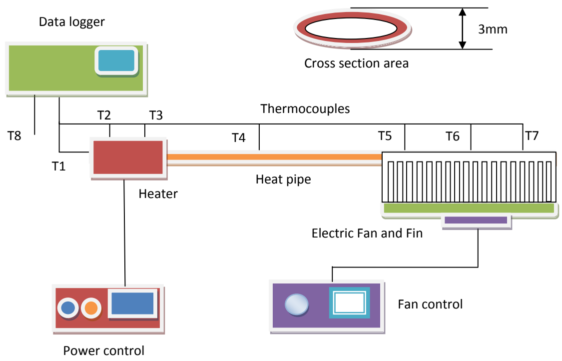

Figure1.Experimental setup

FHP was set in the horizontal direction. It was because the engineering application most requires the FHP using in horizontal direction. The heating block was a copper block which was heated with two heating rods. These heating rods were connected to the transformer, which supplied heating power by adjusting the current and voltage (Q = Volt x current). The length of evaporation section was controlled by the length of heating block which width was 30 mm. The condensation section was cooled by air (25 ^{o}C±0.1 ^{o}C). The length of condensation section was controlled 70 mm. The OMEGA K-type thermocouples (the uncertainty was ± 0.1 ^{o}C) were installed to measure the wall temperature at different positions of FHP. The detailed location of thermocouples was shown in Fig.1. There was insulation cotton packaged outside at adiabatic section in order to avoid heat loss. All tests were conducted at an ambient temperature of 25 ±1 °C. Based on the application requirements, the FHP must operate normally. Thus, when the heat transfer limit (dry-out) appeared, the experiment would be stopped.

3. Results and Discussions

3.1 Effect of temperature distribution

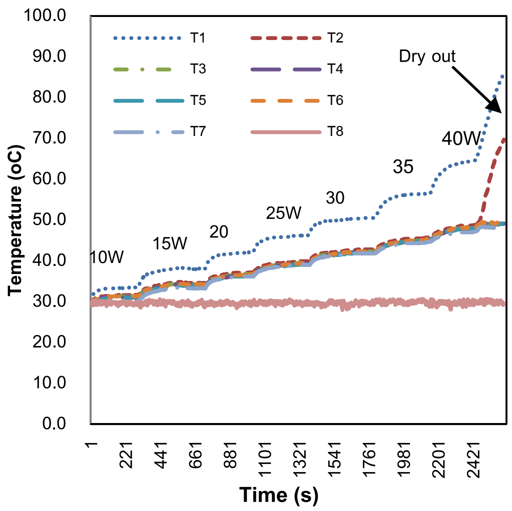

Figure 2. Relationship between temperature distribution and times

Fig. 2 shows temperature distribution of FHP with filling rat 60%. The temperature curve increased with the increased of the heating power .Moreover, the temperatures of evaporation section (T1, T2, T3 and T4) kept rising and without a stable trend at heating power of 40W, the temperatures of evaporation section (T1 and T2) sharply raised and the temperatures of condensation section (T5 T6 and T7) reduced. While the heat transfer limit appeared on FHP. This phenomenon was partial dry out, while the transfer limit appeared on FHP. This trend is same the other filling rates.

3.2 Effect of filling rate on maximum heat transfer rate

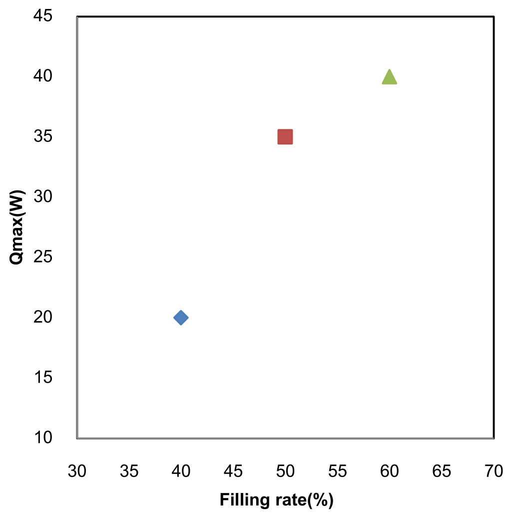

Figure 3. Relation between filling rate with maximum heat transfer rate

From the Fig. 3 show relation between filling rate with maximum heat transfer rate. When the filling rates increases from 40 % to 60 %, the maximum heat transfer rates is increases from 20 W to 60 W. This is because at the small filling rate (40%) the working fluid in wick structure is not saturated , when the heat pipe receives heat input at evaporator section, the working fluid evaporate liquid phase to vapor and transfer heat out at condenser section. The working fluid from condenser returns to evaporator section by capillary pump. So at small heat input (about 5-15 W) the heat pipe can work very well, but when increases heat input more than 20 W the heat pipe cannot transfer heat. This is because the return condense is not enough to evaporator section, dry out occurs in evaporator section heat pipe is not continue to work. When the filling rate increases to 50 % (saturated wick) the maximum heat transfer rate is increase than the filling rate (40%), this because the circulation working fluid flow in continued. But maximum heat transfer rate is 35W these because the heat sink of FHPs is air that has a high thermal resistant it result to the liquid condensate is reduced and not enough to return to evaporator section, dry out occur, thus the heat pipe lead to heat transfer limit. When filling rate is 60 % (a little bit over saturated wick) the maximum heat transfer rate increases a small watt. This is because, although working in a wick that will increase, the heat pipe it transfer heat more than (filling rate 50%) a small watt. Due to when the working fluid continues evaporate from evaporator section but cannot condensate to liquid. The pressure and density of vapor are high; it difficult to condensate and result to the heat pipe cannot work.

3.3 Effect of maximum heat transfer rate on thermal resistant

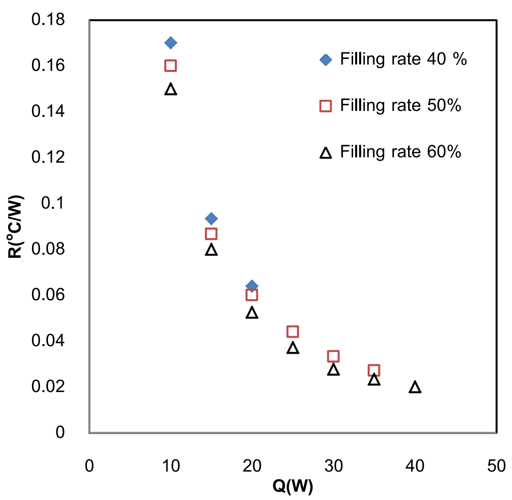

Figure 4. Relationship between heat transfers rates with thermal resistant

Fig.4 as show the heating power increased, the thermal resistance of FHP decreased before the FHP dried out. When filling rate is 40% the thermal resistance of FHP decreased from 0.17 ^{o}C/W at 10 W, and then as the heating power increased to 20 W, the thermal resistance decreased to 0.064 ^{o}C/W at 20 W , after that the FHP is dried out. When filling rate is 50%, the thermal resistance decreased from 0.16 ^{o}C/W at 10 W, and then the FHP dried out after 35W. This trend as the same with filling rate is 60%. This is because when the heating power increase it affect to some property of working fluid ,such viscosity is low that result to liquid condensate convenient to flow from condenser section to evaporator section. After that it result liquid condensate at condenser section is low, so that the thermal resistance reduced. After that when increase heating power more than maximum the dry out occur at evaporator section that case as the reason in fig.3 has previous describe.

4. Conclusion

A series of experiments were performed investigate the effect of effect of filling rate of working fluid on thermal performance flat heat pipe. In the experimental, the filling rates are 40%, 50% and 60% respectively. The FHPs were set to operate at horizontal heating mode. It can conclusion that the filling rate at 60 %, heat pipe can transfer heat maximum is 40 W and the thermal resistant is 0.02 ^{o}C/W.

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