Influence of Filling Ratios on the Thermal Performance of Flat Heat Pipes

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Abstract

This research investigated the effect of the filling ratio on the thermal performance of a flat heat pipes. The flat heat pipes (FHP) used in this study were made of copper and had an inner and an outer diameter of 5.4 mm and 6.0 mm, respectively. Water was used as the working fluids to fill the FHPs during the tests. The wick structure was made from copper powder sintering. The copper tube was compressed into 3.0 mm of thickness; the porosity of wick was 50 ± 5%; and the wick thickness was 0.6 mm. In this work, the four different filling ratios of working fluid were considered: 35, 45, 55 and 65%. The FHPs were set to operate in the horizontal heating mode and input heat load until FHPs cannot work. From the results, the filling ratio of 65% can transfer 50.0W of heat load and 0.013^{o}C/W of thermal resistant.

Keywords: Filling ratios; flat heat pipe; thermal performance; thermal resistant**.**

1. Introduction

Recently, the applications of heat pipe for thermal management is recognized in many industries. In particular, electronic cooling systems have become critical in many products. Electric products have developed small size to fulfill the consumers need. Therefore, the thermal management of electronic equipment has become an important issue because of the increasing power requirements along with the miniaturization of the devices. Thus, heat pipe cooling is needed to develop product to demanding specifications for compactness, reliability and performance. For small electronic equipment, a heat pipe is required to be flat and small and has been identified a having potential in this challenging area of heat dissipation in electronic devices. As a high thermal conductor, a flat heat pipes function in a substantially different manner compared to conventional tubular heat pipe since the former involve a more complex Transport mechanism. An experimental investigation of the thermal performance of a flat heat pipe was studied by Vafai et al.[1]. Analytical models for predicting the transient performance of a flat plate heat pipe for startup and shut down operations were studied by Wang and Vafai [2]. They found that the wicks create the main thermal resistance resulting in the largest temperature drop in the heat pipe. Effective heat transport lengths of flat plate heat pipes with multiple heat sources were studied by Tan et. al [3]. A 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. The analysis of an experimental investigation into the thermal performance of a flat plate heat pipes [4-6]. An investigation into how a thermal spreader can achieve an uniform heat

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flux distribution and thus enhance the heat dissipation of heat sinks of flat plate heat pipe was carried out by Zhang Minget et al. [7]. The combined effects of the filling ratio and the vapour space thickness on the performance of a flat plate heat pipe are presented by Lips et. Al.[8]. They measured the temperature fields in the FPHP for different filling ratios, heat fluxes and vapour space thicknesses and found that the thermal performance depended strongly on the filling ratio and the vapour space thickness.The optimum filling is in the range one to two times the total volume of the grooves. The experiments performed to investigate the effect of evaporation and condensation length on thermal performance of the flat plate heat pipes (FPHP) carried out by Shuangfeng Wang [9]. The 3D numerical and experimental models for flat and embedded heat pipes applied in high-end VGA card cooling system were investigated by Jung-Chang Wang [10]. He obtained simulation results that were in agreement with the experimental results within 5%. Then the effect of capillary pressure on the performance of a heat pipe was numerically investigated with FEM by Nat Thuchayapong et al.[11]. Many experimental studies on the heat transfer characteristics and the applications of flat heat pipes [12-16]. A transient analysis of heat transfer and fluid flows in a polymer-based micro flat heat pipe with hybrid wicks was investigated by Mehdi Famouri et al.[17]. They noted that the transformation point and transformation line criteria were introduced in the analysis for the first time to track the finalization of the evaporation and the beginning of the condensation process.

As discussed, the effect of the filling ratio on the thermal efficiency of heat pipes with different design were investigated by many researchers. However, measurements relevant to an application of flat heat pipes have been not clearly studied yet. Thus, the goal of this paper is to study the effect of the filling ratios on the thermal performance of flat heat pipes with water as a working fluid.

2. Experimental Setup

The experimental apparatus of FHP is shown in Fig. 1. It consists of four sections: the test section, the cool fan section, the heat load section and the record data system. The operational orientation is the horizontal heating mode in which the FHP is set only in the horizontal direction. This is because most engineering applications use FHP in the horizontal direction. The test section is fabricated from a long strip FHP with a total length of 200.0 mm. The flat heat pipes (FHPs) were made of copper and had an inner and an outer diameter of 5.4 mm and 6.0 mm, respectively. The sintered copper power wick structure of 50±5% in porosity and of 0.6 mm in wick thickness. The seal is welded using the argon arc welding technology. The vacuum is established by using a vacuum pump, then the water is filled as a working fluid, and the copper tube was compressed to 3.0 mm in thickness.

A fill ratio refers to the percentage of the void fraction that is filled by the working fluids. The fill ratios used in this experiment were 35%, 45%, 55% and 65% of the flat heat pipe porosity for the different tests.

The evaporator section of FHP (30.0 mm) is supplied by a copper block with two heating rods. These heating rods are connected to a transformer that supplies heating power according to a given current and voltage (Q = Volt x Current). The condensation section (70.0 mm) is cooled by air (25 ^{o}C±1 ^{o}C). Seven thermocouples of the type OMEGA type T (the uncertainty is ± 0.1 ^{o}C) are installed in order to measure the wall temperature at various positions of the FHP (as shown in Fig.1). The cotton is packed around the adiabatic section to avoid heat loss. All tests are conducted at an ambient temperature of 25 ±1 ^{o}C. The experiment is designed to test the performance of FHP based on the application requirements. The heat load is supplied step by step from 5.0W until the FHP leads to the heat transfer limit, dry-out appeared and the experiment is stopped.

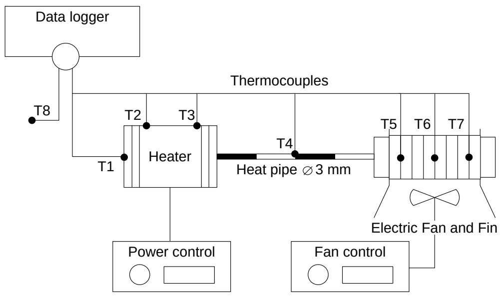


Fig.1. Experimental setup.

3. Results and Discussions

Before present the results and discussions, some properties need to define as follows. The heat load or the input power in the evaporation section is calculated from the supply voltage and the current measurement:

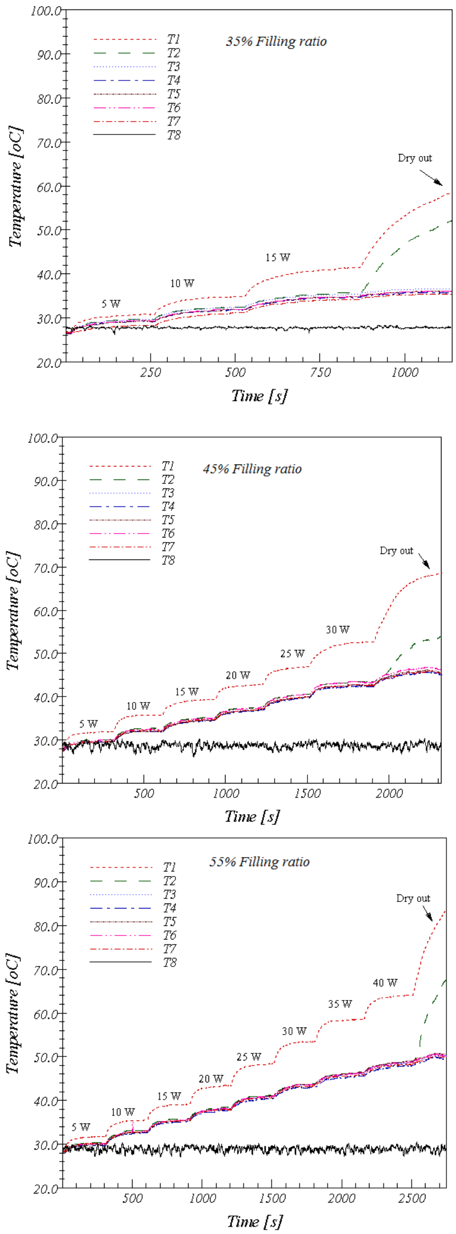
$$Q_{in} = VI \qquad [\text{W}]. \qquad (1)$$

The thermal resistance of FHP is defined as:

$$R = \frac{\bar{T}_e - \bar{T}_c}{Q_{in}} \qquad [^{\circ}\text{C/W}]. \qquad (2)$$

3.1 Analysis of temperature distribution

Fig. 2 shows the temperature distribution of the FHP tests with respect to time of the experiment. From the figure, T1 to T7 are the wall temperatures of the FHP while T8 is the ambient temperature. Fig. 2(a), 2(b), 2(c) and 2(d) correspond to 35%, 45%, 55% and 65% filling ratio, respectively. In fig. 2(a), at 5.0W of heat load, the temperature T1 (heater) increases from 26.5 ^{o}C to 30.5 ^{o}C ; T2 and T3 (evaporator section) increase from 26.5 to 29.5 ^{o}C; T5, T6 and T7 (condenser section) increase from 26.5 ^{o}C to 28.5 ^{o}C. The outcome resulting from increasing heat load (10.0 and 15.0W). However, the difference temperature between T1 and T2, and T1 and T3 are about 3.0^{o}C and 6.0^{o}C, respectively. When more than heat loads of more than 15.0W is applied, the T1 and T2 rise sharply while T5 T6 and T7 decrease. This means that the heat transfer limit to transfer on to the FHP causes a part of the FHP to dry out. Varying the filling ratios yield outcomes that follow a similar trend.



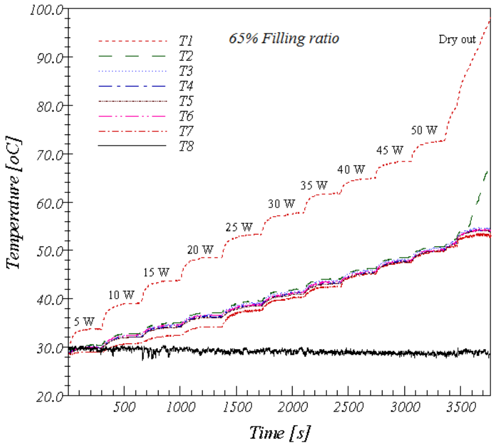


Fig.2. Variation of temperature distribution along the FHP surface.

3.2 Analysis of filling ratio on maximum heat transfer rate

Fig. 3 shows the influence of the filling ratio on the maximum heat transfer rate. It can be seen that the maximum heat transfer rate (Q_{max}) increases (from 15.0W to 50.0W) with increasing filling ratio (from 35% to 65% of FHP porosity). Applying heat in the evaporation section causes the liquid to boil and vaporize. The vapor with high pressure moves into the condenser section. After it condenses, the working fluid moves back into the evaporator section due to the capillary pump force. Thus, an increase in the heat load leads to an increase in the evaporator temperature, which in turn corresponds to the higher evaporation heat transfer rate to working fluid. At a low filling ratio of working fluid, the porous wick structure is not saturated. The condensate is not enough to fill to evaporator section. A dry out zone occurs in evaporator section. Finally, the heat pipe stops working.

An increase in the filling ratio (from 35% to 65% of FHP porosity) results in an increase in the maximum heat transfer rate. This is because the working fluid can continuously circulate. It is also found that the maximum heat transfer rate is obtained at the filling ratio of 65% in FHP porosity.

At the filling ratio of 45% in FHP porosity, the maximum heat transfer rate is 30.0W. It is better than that at the 35% filling ratio because the working fluid can flow continuously. Then, at 55% of FHP porosity (saturated wick), the maximum heat transfer rate becomes to 40.0W. At this point, dry out occurs in the evaporator section when the input heat load was more than 40.0W. This is because the heat sink of the FHPs is air that has a high thermal resistance, resulting in a reduction in the liquid condensate. When not enough condensate returns to the evaporator section, the heat pipe then reaches the heat transfer limit. Finally, at 65% of FHP porosity (over saturated wick), the maximum heat transfer rate is 50.0W. It is observed that the FHP can transfer heat more than in the case of 55% filling ratio. However, the FHP cannot work at heat load over 50.0W. This is because the pressure and the density of vapor are high; it is difficult for the water to condense to liquid. These results lead to a drop in the liquid pressure in the condenser section. This pressure drop results in a drop in the amount of liquid in the evaporator section leading to insufficient support for the heat load. The end of the evaporator section ends up with a dry out zone. Finally, the FHP stops working.

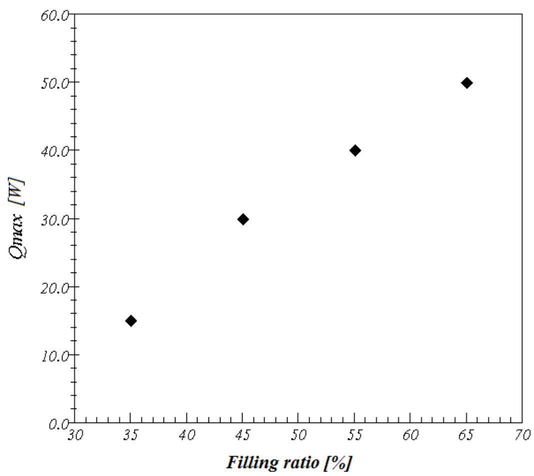


Fig.3. Relation between filling ratio and maximum heat transfer rate.

3.3 Analysis of filling ratio on thermal resistance

Fig. 4 is a plot of the thermal resistance against the heat load for different filling ratios of FHP porosity. The thermal resistance can be calculated by using Equation (2). It can be seen that the thermal resistance decreases with the increasing heat load. From Fig. 4, the thermal resistance of FHP decreases from 0.136^{o}C/W to 0.066 ^{o}C/W when the heat load is increased from 5.0W to 15.0W at 35% filling ratio. Also at 65% of filling ratio, the thermal resistance decreased from 0.130^{o}C/W to 0.013^{o}C/W when the heat load is increased from 5.0W to 50.0W. It is found that thermal resistance tends to decrease with increasing heat load for every filling ratio. This is because increasing heat load lowers the temperatures between the evaporator and the condenser sections. In addition, the increase in heat lowers the viscosity of the working fluid while increasing the liquid pressure in the condenser section causing the pressure to be higher than the evaporator section. The end result is an easy flow from the condenser section to the evaporator section allowing the heat pipe to operate in a steady state. Therefore, the thermal resistance deceases since the heat load has increased, these results are in agreement with Nat Thuchayapong et al.[11]. This is because the vapor pressure in the vapor channel is high, leading to a reduction in the condensation of the working fluid in the condenser section. Thus, the amount of liquid condenses and the capillary pressure are low, and only a small amount of liquid returns to the evaporator section. This condition results in the pipe drying up, which in turn causes the heat transfer of the heat pipe to be limited. This result is in agreement with Yan-Jun Chen et.al[16].

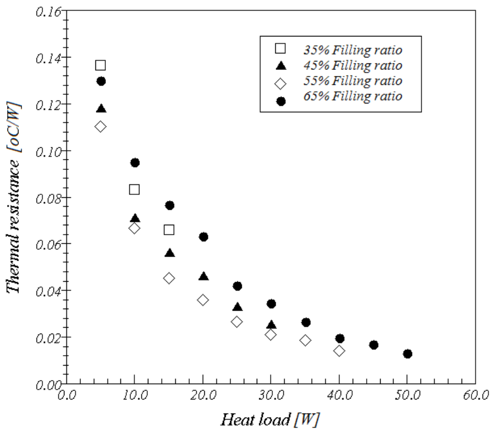


Fig. 4. Variation of thermal resistance with heat load for different filling ratio.

4. Conclusion

A series of experiments are performed to investigate the influence of the filling ratio of working fluid on the thermal performance of flat heat pipes. In this work, the filling ratios at 35, 45, 55 and 65% of FHP porosity are carried out. The FHPs are set to operate in the horizontal heating mode so that they correspond to most engineering applications. It is found that the filling ratio is 65% of FHP porosity; heat pipe can transfer heat maximum is 50.0W; and the thermal resistant is 0.013^{o}C/W.

5. Acknowledgements

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