Thermal Performance of a Loop Thermosyphon

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Abstract

Experimental investigations were performed on a loop thermosyphon, consisting of a condensation section and an evaporation section. The evaporator chamber used in this study has an inside diameter of 25 mm and a height of 25 mm. Three evaporators, without wick structure and with 1 mm and 4 mm thickness wick structures were examined in the test. The experiments were conducted under the condition of 20 °C, 30 °C, 40 °C and 50 °C cooling water, for heating powers from 20 to 250 W, working fluid fill ratios of 5%, 10%, 20%, 30%, 40% and 50%. The experiments used methanol and water as the working fluid. When the system reached the steady state, the temperature was recorded in order to evaluate the performance of the thermosyphon. Effect of cooling water temperatures, fluid fill ratio and evaporator type were studied. Finally, the results show that the wick structure can enhance the heat transfer effects directly. The working fluid water can support a large heating range.

Key Words: Loop Thermosyphon, Enhanced Boiling, Copper Sinter

1. Introduction

Packaging and thermal management of electronic equipment has led to the demand for new and reliable methods for electronic cooling. Because of increased power levels and miniaturization of the electronic devices, typical cooling techniques such as conduction and forced convection are not able to cool such a high heat flux. The increasing integration of electronic systems requires an improved cooling technology. Thermosyphon can be designed either as a single tube or as a closed loop.

An advanced loop thermosyphon consists of an evaporator, where liquid boils and a condenser, where vapor condenses back to liquid; riser and down comer connect these parts. The thermosyphon is a passive heat transfer device, which relies on gravity for the liquid return to the evaporator. Heat is transferred as heat of vaporization from the evaporator to the condenser. Thermosyphon cooling is one of the most promising, being capable of dissipating high heat fluxes with minimal temperature differences.

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Ramaswamy et al. [1,2], used the enhanced structure consists of a stacked network of interconnecting channels in the loop thermosyphon. The effect of varying the pore size, pitch and height on the boiling performance was studied. M. H. Beitelmal et al. of HP, Inc. [3] applied the same enhanced boiling structure as Ramaswamy to the loop Thermosyphon and installed in a computer to test. R. Khodabandeh et al. [4,5], used vertical channels for enhanced boiling structure in loop thermosyphon. D. Khrustalev of Thermacore, Inc. [6] developed the two loop Thermosyphon (LTS) with a sintered copper capillary structure. P. E. Tuma et al. of 3M, Inc. [7] developed the loop Thermosyphon with a sintered copper enhanced structure that was an array of square copper pin fin and used HFE $C_3F_7OCH_3$ as working fluid. J. W. Klett et al. [8] utilized the high thermal conductivity graphitic foam as the evaporator in a modified thermosyphon. The temperatures less than 71 °C have been achieved at heat fluxes of 150 W/cm^2. E. G. Merilo et al. [9], studied the effect of thickness of sintered copper on the critical heat flux. The experiments were performed at atmospheric pressure with water as working fluid. The result show the 1.14 mm thickness bedspread wick reached the highest

heat flux of 310.1 W/cm^2 at a temperature difference of 18 °C.

Methanol and water are used as the working fluids in this study. The present report contains experimental finding on effect of cooling water temperature, comparisons among three evaporators – no wick structure, 1 mm and 4 mm thickness wick structures, optimal fill ratio, etc.

2. Design and Experimental Setup

2.1 Loop Thermosyphon Design

The loop thermosyphon design is schematically shown in Figure 1. The loop thermosyphon consists of an evaporator, a condenser, a vapor line and a liquid line. When heat is added to evaporator, liquid is vaporized and moves through vapor line to condenser where heat is removed. Then the vapor condenses back into evaporator through liquid line and the cycle repeats. All parts are made of copper, and welded together. The evaporator is composed of a chamber and a bottom plate with sintered copper porous for enhanced boiling structure. A heat-resistant O-ring placed in the grooves on the chamber and the bottom plate sealed the two components together. The bottom plate assembly was attached to the chamber flange using hex head screws. The inner diameter of evaporator is 25 mm, and height is 25 mm. The condenser consisted of 7 vertical smooth copper tubes (4 mm OD, 80 mm length). The condenser has one vapor and one liquid header made of copper tubes (12 mm OD, 80 mm length). The condenser is covered with acrylic plates that have cooling water inlet and outlet. The condenser outer dimensions are 90 mm × 19 mm × 106 mm. The vapor line and liquid line are welded to the evaporator leading to the condenser.

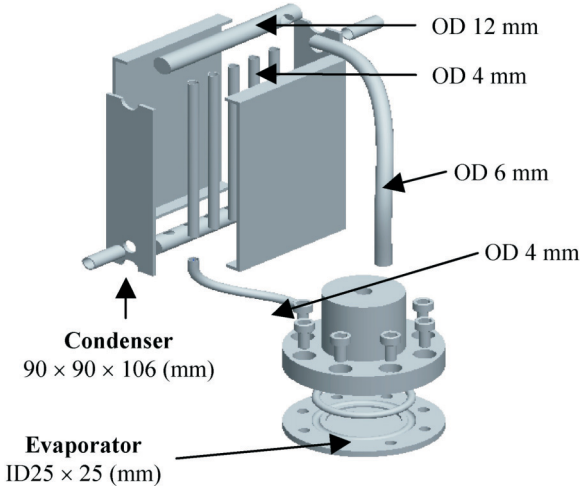

Figure 1. Schematic of loop thermosyphon.

2.2 Enhanced Boiling Structure

The first type evaporator is flat and smooth boiling surface without wick structure. The second and third type evaporators are 17 mm square with 1mm and 4 mm thickness of sinter copper respectively. The sinter copper powder average size is 185.5 μm, the porosity is about 0.5. The scanning electronic microscope (SEM) image of sinter copper is shown in Figure 2.

2.3 Experimental Apparatus

Experimental apparatus consists of heater, power supply, cooling water thermostat, flow meter, temperature acquisition instruments and PC. The cartridge heater is embedded in a square aluminum rod of 31 mm × 31 mm cross-section. The two thermocouples (PT-100) are installed in the top and bottom of aluminum rod. The two thermocouples are used to calculate the heat flux of aluminum rod and the surface temperature. The thermocouples (T type, diameter 0.5 mm) are installed in the bottom plate of evaporator, the inlet and the outlet of evaporator, the inlet and the outlet of condenser and the inlet and the outlet of cooling water. The cooling water inlet set in the bottom of condenser, and outlet in the top of condenser. The flow rate of cooling water was set at 0.2 L/min. The schematic of experimental apparatus is shown in Figure 3.

The heating system used a bar material thermal conduction test system. By the conception of Fourier Law

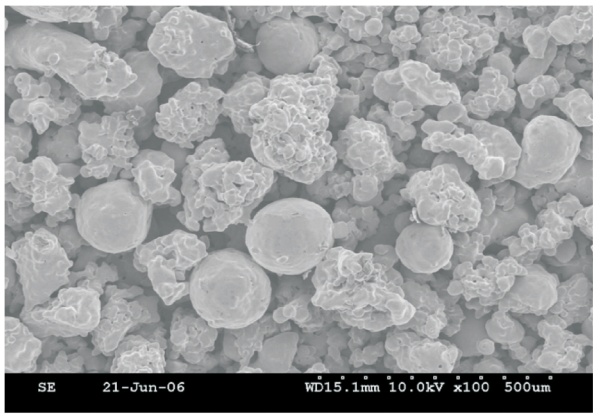

Figure 2. Scanning Electronic Microscope image of sinter copper.

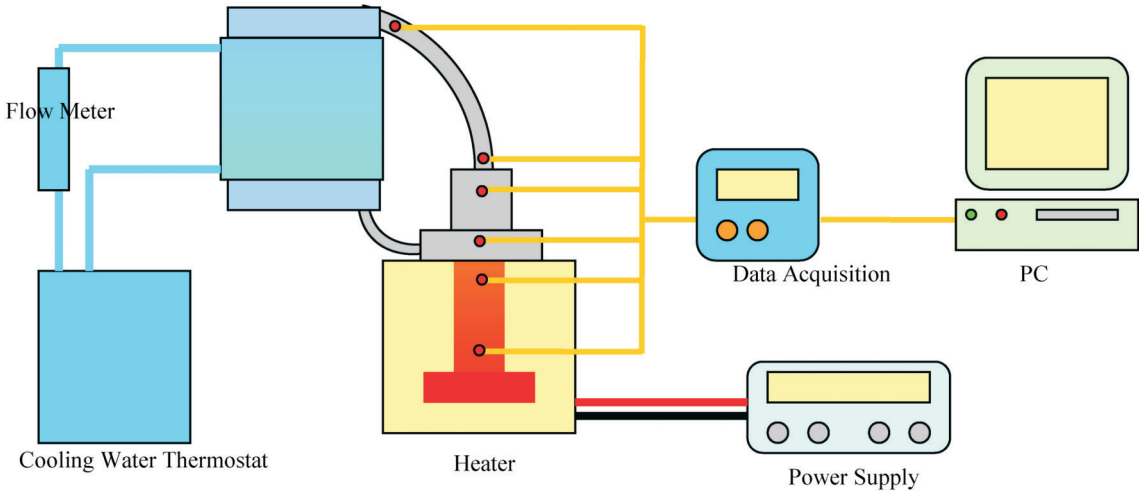

Figure 3. Schematic of experimental apparatus.

and ASTM-5470 D Thermal Guard to calculate the heater surface temperature, thermal resistance and the actual heat transport rate.

3. Experimental Result and Discussion

This experiment utilizes DC Power supply to offer evaporator a steady heating power. Methanol and water are used as the working fluid. The test was investigated under six different working fluid filling ratios in thermosyphon incorporating smooth plate without wick structure and two different height wick structures. The experiments were conducted under the condition of 20 °C, 30 °C, 40 °C and 50 °C cooling water, for heating powers from 20 to 180 W. When the system reached the steady state, the temperature was recorded in order to evaluate the performance of the thermosyphon.

3.1 Effect of Cooling Water Temperatures

Figures 4 and 5 show the variation of the evaporator surface temperature (heater surface temperature) and the thermal resistance as a function of the heat load for 10% fill methanol with 1 mm thick wick respectively. The heater surface temperature increased and the thermal resistance decreased with an increasing cooling water temperature as expected.

3.2 Effect of Filling Ratio

Figure 6 shows the variation of the heater surface temperature as a function of the heat load for methanol working fluid fill ratio of 5%, 10%, 20%, 30%, 40% and 50% without wick structure while the cooling water temperature was kept constant at 20 °C. It can be seen that the lowest heater surface temperature may be obtained for liquid fill ratio of 10% over the examined range of input heat load. Thus, this presents the optimum fill ratio.

Lower fill ratio as 5% and higher fill ratio such as 20% result in worse thermal performance of the loop thermosyphon. The corresponding largest heat load at 70.6 °C heater surface temperature for the evaporator

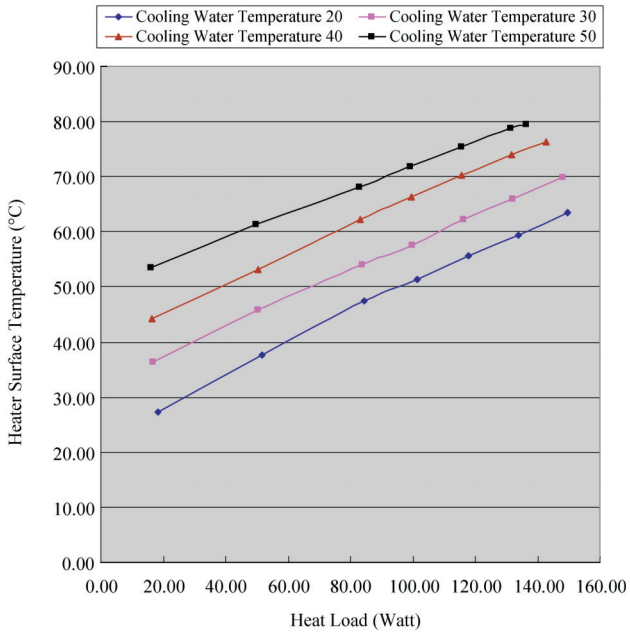

Figure 4. Effect of cooling water increase on the heater surface temperature.

with 10% methanol fill is 150 W in this test.

Figures 7 and 8 show the variation of the heater surface temperature as a function of the heat load with 1 mm and 4 mm thickness wick structure at 6 different methanol fill ratio respectively. From the measurement, the optimal fill ratio for the two cases is around 10%.

In Figure 9 to 11 the results have also been plotted as heater surface temperature with respect to the heat load

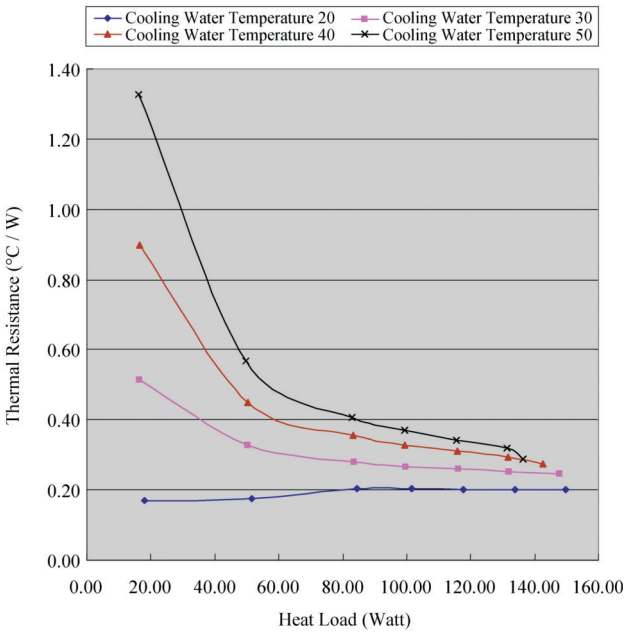

Figure 5. Effect of cooling water increase on the thermal resistance.

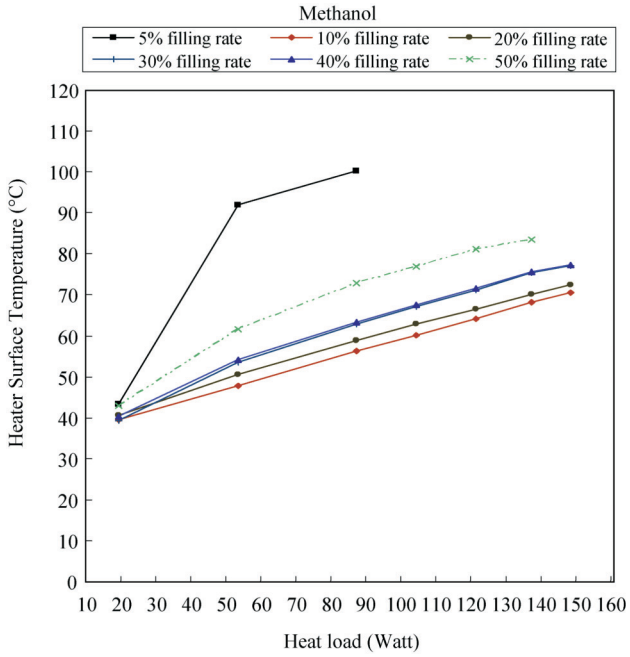

Figure 6. Variation of the heater surface temperature as a function of the heat load for methanol working fluid without wick structure.

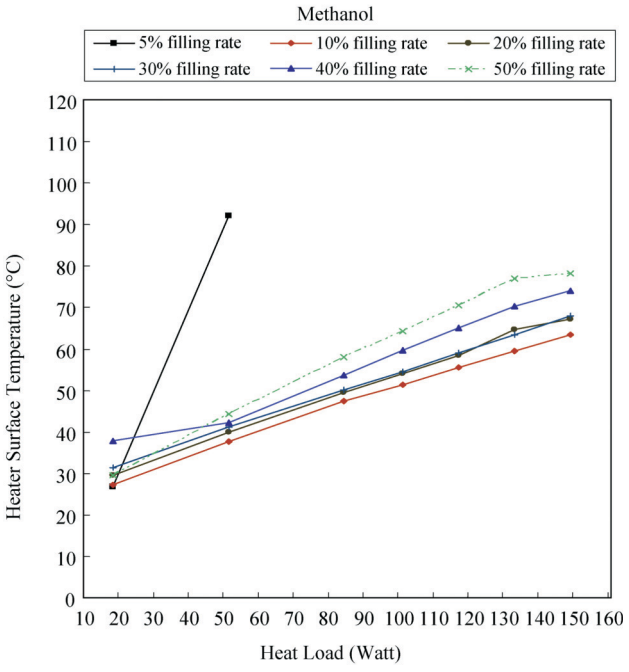

Figure 7. Variation of the heater surface temperature as a function of the heat load for methanol working fluid with 1 mm wick structure.

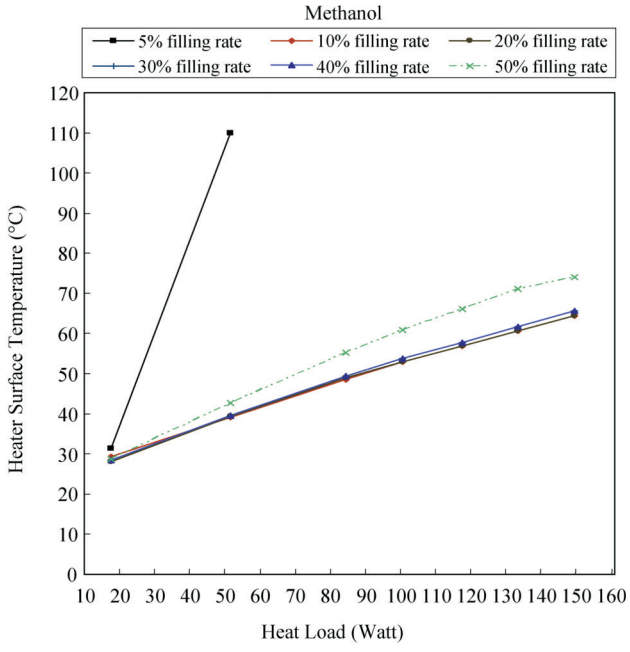

Figure 8. Variation of the heater surface temperature as a function of the heat load for methanol working fluid with 4 mm wick structure.

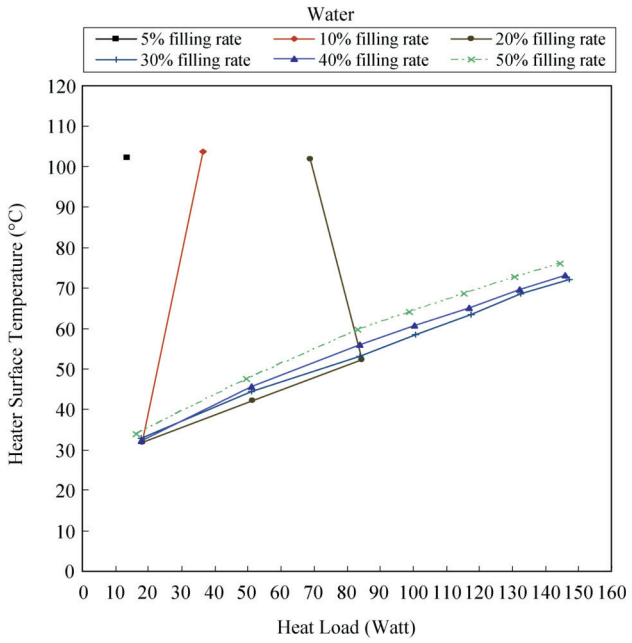

Figure 9. Variation of the heater surface temperature as a function of the heat load for water working fluid without wick structure.

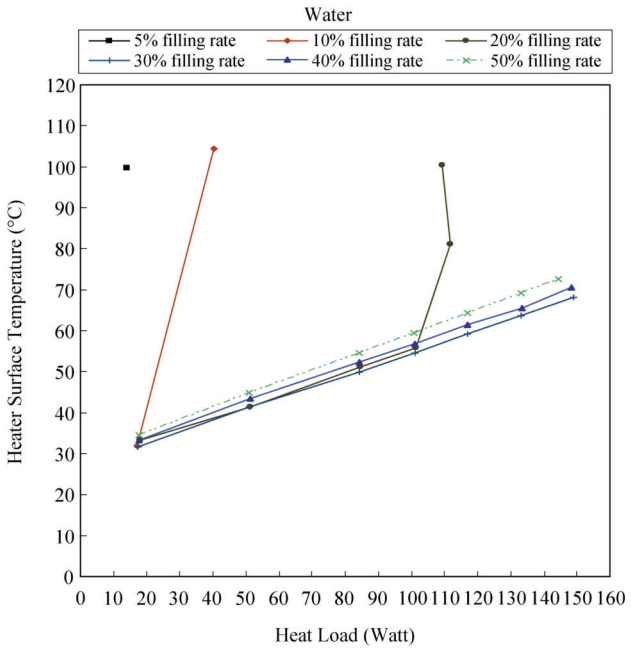

Figure 10. Variation of the heater surface temperature as a function of the heat load for water working fluid with 1 mm wick structure.

for the evaporators without wick structure, with 1 mm and 4 mm thick wick structure at 6 different water fill ratios.

As shown in the figures dry out occurred at lower heat load for 5% and 10% fill ratio and was attributed to a lack of liquid flow back to the evaporator. In Figures 9 11, transition film boiling occurred at about 82 W, the heater surface temperature will increase, and the heat flux is controlled by it, and the heat load will decrease. Same result can also be seen in Figure 10 when heat load is reaching 100 W.

3.3 Effect of Evaporator Type

Three evaporators, without wick structure, with 1 mm and 4 mm thickness wick structures were examined. Figures 12 and 13 show the variation of the heater surface temperature and thermal resistance as a function of the heat load for the 3 types of evaporators with 10% methanol fill ratio. It can be seen that the lowest heater surface temperature may be obtained in the evaporator with 1 mm thickness wick structure over the examined range of input heat load. For 150 W heat load, the highest temperature 70.5 °C occurs in the evaporator without wick structure, whereas the temperatures in the evaporator with 1 mm thickness wick structure is 63.5 °C. Figures 14 and

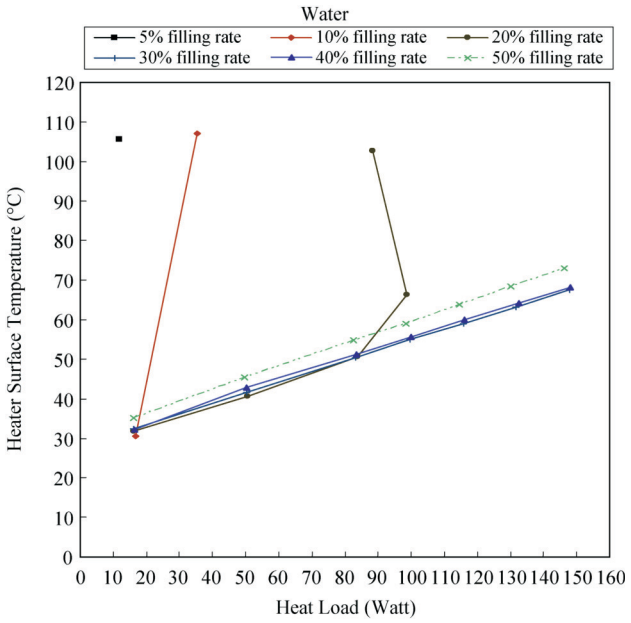

Figure 11. Variation of the heater surface temperature as a function of the heat load for water working fluid with 4 mm wick structure.

15 show the variation of the heater surface temperature and thermal resistance as a function of the heat load for the 3 types of evaporators with 30% water fill ratio respectively. As shown in the Figure 14 the lowest heater surface temperature also occurs in the evaporator with

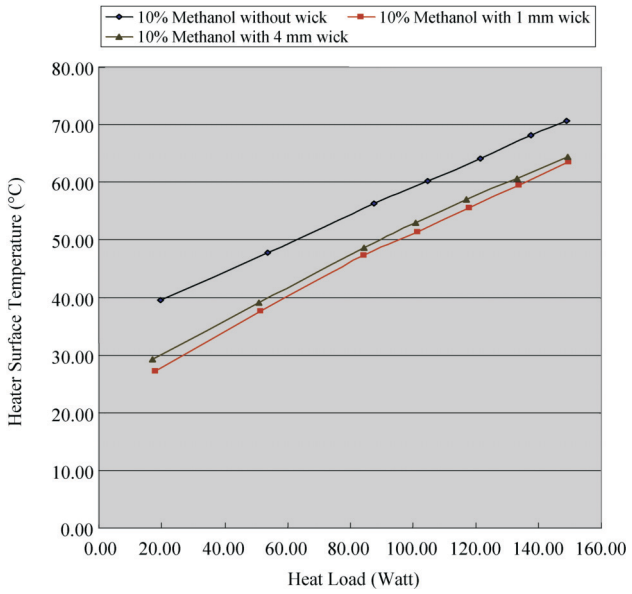

Figure 12. Variation of the heater surface temperature as a function of the heat load for the 3 types of evaporators with 10% methanol fill ratio.

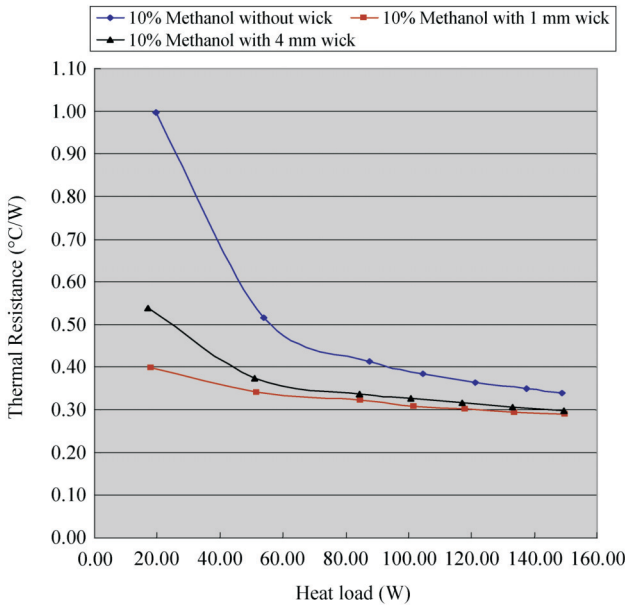

Figure 13. Variation of the thermal resistance as a function of the heat load for the 3 types of evaporators with 10% methanol fill ratio.

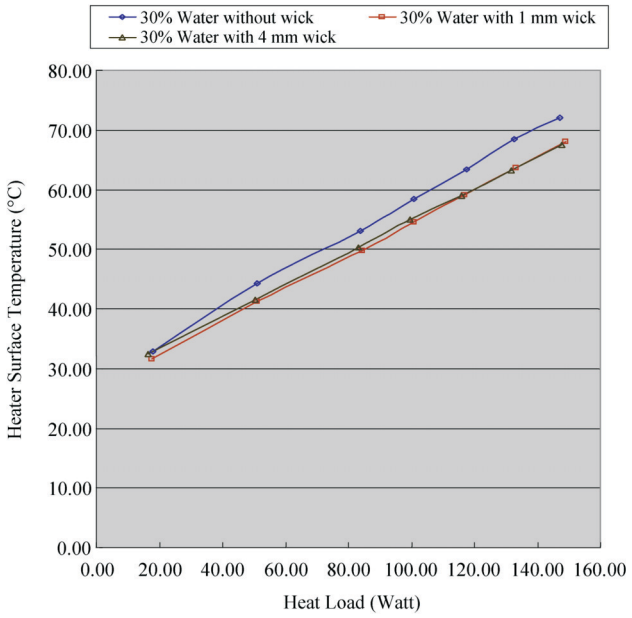

Figure 14. Variation of the heater surface temperature as a function of the heat load for the 3 types of evaporators with 30% water fill ratio

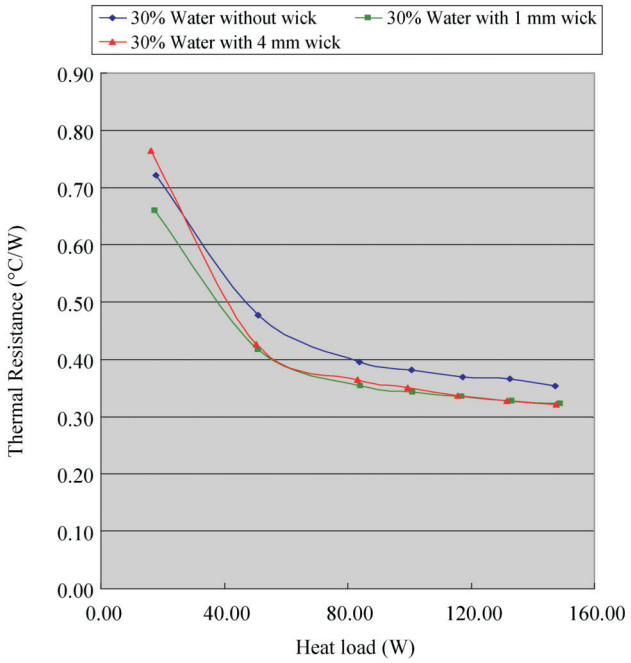

Figure 15. Variation of the thermal resistance as a function of the heat load for the 3 types of evaporators with 30% water fill ratio

1 mm thickness wick structure. The highest temperature 72.1 °C occurs in the evaporator without wick structure, whereas the temperatures in the evaporator with 1 mm thickness wick structure is 68 °C.

From Figures 12 and 15, we can find the evaporator with 1 mm wick structure present a good performance when heat load is below 50 W. When heat load is over 50 W both the 1 mm and 4 mm wick structure evaporators show their performance with a small thermal resistance difference.

Finally, the experiments were conducted under the

condition of 20 °C cooling water, for heating powers from 130 to 265 W. Figure 16 shows the variation of the heater surface temperature as a function of the heat load for the working fluid with 10% methanol fill ratio and 30% water fill ratio. The result shows that heater surface temperature for 10% methanol is lower than 30% water in the heat load range from 130 to 243 W. Evaporator with 10% methanol dry out at 243 W. As heat load increase to 265 W, the evaporator with 30% water will remain operate without dry out. The lower boiling point of methanol and higher latent heat of water contribute to these results.

4. Conclusion

The experimental study on the performance of a methanol and water loop thermosyphon has been carried out. The main results are summarized as follows:

1. The experimentally determined optimal fill ratio is suggested to be 10% with methanol and 30% with water. This is for this sinter wick and design. Other wicks and designs will have different optimum ratios.
2. Enhancing the boiling in the evaporator by sintered copper wicks structures, reduces the heater surface temperature. The temperature of evaporator with 1 mm wick is reduced by approximately 10% in comparison with that of evaporator without wick for the heat load of 150 W.
3. The methanol loop thermosyphon achieved better performance than water loop thermosyphon. Given an actual heating power of 243 W, heater surface temperature of 77.8 °C and thermal resistance of 0.24 °C/W.
4. The Water loop thermosyphon remain operate without dry out as heat load increase to 266 W, producing a heater surface temperature of 91.4 °C and thermal resistance of 0.27 °C/W.

The lower boiling point of methanol and higher latent heat of water contribute to these results. Further tests include start-up, power ramp up, high power, rapid power changed, and rapid sink temperature change should be performed for the practical application.

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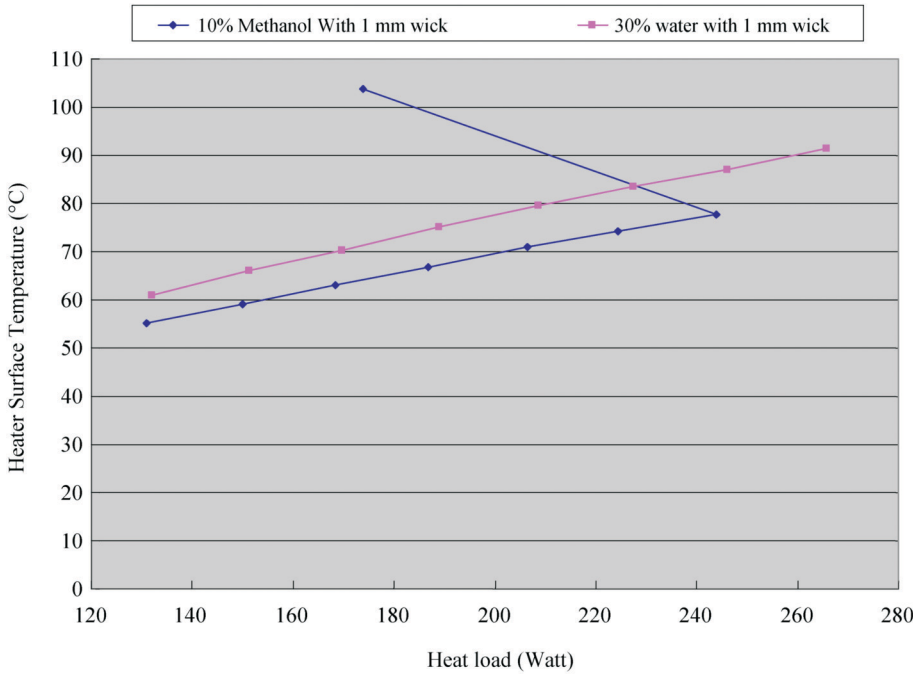

Figure 16. Variation of the heater surface temperature as a function of the heat load for 10% methanol fill ratio and 30% water fill ratio with 1 mm wick structure.

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