Investigation of copper-water loop heat pipe for different filling ratios

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Abstract: The present work reported here involves the experimental investigation and performance evaluation of loop heat pipe (LHP) with flat evaporator and wick made up of stainless-steel mesh. The experiment is conducted for different fill ratio such as 40%, 50%, 60% and different heat loads of 20 W, 40 W, 60 W, 80 W and 100 W using De-Ionized water as fluid for electronic cooling applications. And evaluated operating performance of loop heat pipes for both steady and transient state. The evaporator, condenser, liquid line and vapour line are made up of copper and are placed in horizontal orientation. The results show Under forced water-cooling condition with the cooling water temperature of 25 °C, the LHP can transfer a maximum heat load of 100 W with the evaporator temperature of 92˚C and a minimum thermal resistance of 0.5332 ˚C/W.

1. INTRODUCTION

The recent advancement in electronic industry in terms of making advanced electronic devices needs cooling of these devices for terrestrial and space applications. Since heat pipes is such a device that can be easily integrated into these devices to remove the heat that is generated. The heat pipes are the passive devices that can operate in any adverse conditions such as working against the gravity, compact, lightweight and low cost makes them so popular to use in cooling technology. Many researchers conducted experimental and numerical studies to develop these devices some of them are discussed in this article. Miniature ammonia loop heat pipes with different orientation for terrestrial applications using infrared thermography. m-LHP can easily release a heat load up to 225 W (with vaporiser temperature of 70°C) and allowable thermal resistance of 0.5 K/W [1]. In this article authors have investigated experimental and visualization studies to evaluate the thermal performance of loop heat pipe for terrestrial applications. Experiments have been conducted to study both the start-up stage and formation of vapour bubbles inside the evaporator and finding the thermal resistance parameter. According to study LHP can easily sustain the maximum heat load of 550 W (evaporator temperature 91.2°C) and lowest thermal resistance of 0.068 K/W [2]. Different wick surface morphology and fill ratio studied for heat load operating between 5 to 200 W. and results have shown that rough porous copper fibered sintered sheets exhibited lower thermal resistance [3]. The outcome of this research for effect of filling ratio for dissimilar diameter liquid and vapour transport lines for the assessment of heat transfer rate of micro loop heat pipe (mLHP) working under heat load between 20-380 W was they have found 30% filling ratio is optimum value for high heat transfer rate [4]. Developed and investigated miniature loop heat pipe (mLHP) working with acetone as circulating fluid.

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fluid and varying heat load between 5-60 W under different orientations. And lowest thermal resistance of the system was 0.16 °C/W irrespective of orientation of the system [5]. Studied the result of peripheral parameters on the working of the loop heat pipe operating between 20-600 W with 0-60° orientation and concluded that it can easily transfer heat load between 400 to 600 W with a minimum thermal resistance from the system of 0.02 °C/W [6]. Experimental and visual studies are carried out for condensation and recirculation of fluid inside the loop heat pipe (LHP) using flat evaporator and flat gap condenser to examine the heat transfer and vapour condensation inside the condenser for heat load varying between 20 to 500 W and for different condenser temperatures such as 20 °C, 40 °C and 60 °C [7]. 3D model has been developed for simulation of flat evaporator of loop heat pipe to study the thermal process considering into account of one-sided heat load supply, features of the configuration and geometric parameters of the evaporator and its structural elements. And also studied phenomenon of wick drying, the process of uniform and concentrated heat supply to the evaporator for the heat load varying between 20 to 1100 [8]. Complete experimental study have been conducted for copper water LHP for boiling and evaporation of working fluid inside the loop heat pipe using infrared camera for heat load up-to 600 W [9]. Addressed thermal characteristics of the miniature loop heat pipe(mLHP) for start-up behaviour at low as well as at high heat loads and found that at low heat loads time taken by the system was very high, for the step and random power cycles time taken was short and operating thermal resistance was 0.17 °C/W for heat load of 70 W [10]. Since the available research data reveals that not many experimental studies have been conducted to determine performance of loop heat pipes with copper- water stainless steel wick combination for heat load up-to 100 W. so in this study investigations are done to test the LHP test rig to transfer heat load up-to 100 W when LHP is positioned in the horizontal orientation with different fill ratios of working fluid.

2. EXPERIMENTAL DETAILS

![Schematic diagram of experimental setup](image)

The experimental test rig is shown in figure 1. It mainly contains the flat evaporator integrated with compensation chamber (cc) and Stainless-steel mesh wick, condenser made-up of copper plate, copper pipe used as liquid line, vapour line and charging line. Evaporator was fabricated using copper metal plate with inner space measuring 65*40*5 mm with stainless steel mesh porous wick 5 mm to generate capillary force for the vapour to move from compensation chamber to vapour line. O-ring seal is used to wrap between the evaporator and evaporator cover plate, was tightened together with stainless steel screws. Condenser was fabricated with copper metal plate to cool the liquid. The system is cooled by continuous supply of cooling water at the rate of 1.35 L/min through the cooling line with the help of overhead water tank. Measured quantity of circulating liquid is filled through charging line
into the compensation chamber.

As illustrated the experimental test rig mainly consisted of the heating system, LHP, the cooling system and data acquisition system. Heat is supplied with a flat mica heater with 250 W capacity to the evaporator and it was sealed with the help of woven glass wool to avoid heat loss to atmosphere. The data acquisition connected to computer will record the temperature data obtained from T-type thermocouples. The system was positioned in horizontal direction as both the evaporator and condenser section on same line. There are mainly six T-type thermocouples are used to measure the temperature data from the surface of the loop heat pipe at required positions on the test rig. The experiment is conducted for different heat loads like 20W, 40W, 60W, 80W and 100W respectively.

3. TESTING PROCEDURE

The schematic set-up for experimental studies is shown in figure 1. Experiment is conducted for different heat input and for different filling ratios using De-ionized water as working fluid.

The following procedure is adopted for experimental test rig.

- Before charging the working fluid into LHP, it is evacuated completely and care was taken such that there will not be any air present inside the LHP.
- Once it is evacuated measured quantity of working fluid is charged through the charging line into the compensation chamber.
- Required heat input is supplied with the help of power supply which is connected to Mica-heater of maximum capacity 250 W.
- There are six T-type of thermocouples are attached to the surface of the LHP at required positions to measure the temperature data.
- The system is cooled by running Cooling water at the rate of 1.35 L/min.
- The experiment is repeated for varying heat supply ranging from 20-100 W with an increment of 20 W in each step for 40 %, 50 % and 60 % filling ratios.
- The experiment was conducted for both the steady and transient state of LHP.

4. RESULTS

4.1 Effect of fill ratio

The experiment is conducted for 40%, 50% and 60% fill ratio using Deionized water as working fluid to evaluate thermal characteristics of LHP.

From the figure 2 it is seen that when the head load is increased, thermal resistance of the LHP decreases for 60% fill ratio and heat transfer rate of LHP increases with higher heat loads and lower thermal resistance.

Figure 3 variation of heat transfer coefficient with heat load. It can be concluded that heat transfer coefficient gradually increases with increase in heat load. At the higher heat load LHP gives better heat transfer results and makes it suitable to use in terrestrial electronic applications.
Transient experimental studies are conducted for varying heat loads from 20 W to 100 W with an increment of 20 W for 60 % fill ratio using Deionized water as circulating fluid.

From the figure 4 it shows that variation of evaporator temperature with time for different heat load. it is seen that to achieve the steady state of LHP with low heat load it takes time around 1400 s and after that it starts to work i.e., the circulation of working fluid inside LHP begins. And also, it can be concluded that evaporator temperature goes on increasing with increase in heat load and with increase in time rate. Because of the energy level of the fluid increases as the heat load increases. Figure 5 shows the variation of Condenser temperature with time for different heat load. The vapour which is carried in vapour line needs to be condensed and should be recirculated back to compensation chamber (cc). from the figure 5 it is seen that condenser temperature increases with increase in heat load and time. It is observed that initially for low heat load condenser temperature is low and rate of momentum of the fluid inside the LHP takes time around 600 s and after that once the temperature reaches maximum level the fluid circulation and condensation rate increases. The heat carried away by the vapour line gets condensed into liquid and it sent back to cc through the liquid line.

Figure 6 It represents the temperature difference v/s time. It shows that steady state is achieved at a faster rate, around 500 s. The rate of circulation of fluid inside the LHP begins quickly and heat transfer rate increases with increase in time for different heat input supply.
4.2 Effect of heat input

Experimental studies on LHP are carried out for varying heat inputs such as 20 W, 40 W, 60 W, 80 W and 100 W with different fill ratio of circulating fluid. Below graphs shows the results for 60 W heat input and 40%, 50% and 60% fill ratio.

Figure 7 It is seen that for all fill ratio time taken to achieve the steady state is around 800 s with evaporator temperature of 38˚C for 60% fill ratio, 45˚C for 50% fill ratio and 56˚C for 40% fill ratio. From the results it can be concluded that 60% fill ratio is the optimum value for higher heat transfer rate. Since in this case the LHP starts early at low temperature and reaches the steady state.

Figure 8 It shows the results for varying fill ratio for 60 W heat input. From the results it can be concluded that for 60% fill ratio time taken to achieve the steady state is around 900 s with low condenser temperature of 26˚C.

Figure 9 shows the results for temperature difference v/s time for varying fill ratio. It is seen that initially, the temperature difference is higher for lower fill ratio of 40%, but when the system reaches steady state, this temperature difference increases with increase in fill ratio of 60%. So, from the study we can conclude that higher fill ratio gives better thermal performance for LHP. And possibility of wick dry out will be less.

Figure 10 shows the results for thermal resistance v/s heat input. From the figure, it is clear that thermal resistance decreases for higher fill ratio as well as higher heat input. And it gives better results of heat transfer characteristics for the LHP. So, the performance of LHP can be improved.
5. CONCLUSION

In this article it provides the information about the investigation of LHP for terrestrial cooling applications, studies have been conducted for fabricated LHP system to test the thermal characteristics for different heat input and fill ratio. From the study it can be concluded that for higher fill ratio and higher heat input the operation of LHP will begin at a faster rate as compared to low fill ratio and low heat input. As per the study LHP can effectively dissipate heat load of 100 W with minimum thermal resistance of 0.5332 °C/W with evaporator temperature of 92 °C working in horizontal orientation.

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