ABSTRACT

The present investigation on a miniature loop heat pipe (LHP) with flat evaporator is motivated by two factors. Firstly, miniature loop heat pipes are required for thermal management of small electronics in spacecraft with heat dissipation ranging from 50 W to 100 W (heat flux up to ~ 10 W/cm^2). An LHP with flat evaporator is easier to mount on an electronic package (*heat source*) without a saddle. Though axially grooved aluminium – ammonia heat pipes are being used for thermal management in spacecraft, when the electronic package is located far away from the radiator, conventional heat pipes are no longer useful as the number of bends in axially grooved heat pipes is restricted. LHPs can overcome this issue since they have smooth walled tubes for vapour and liquid transport lines that can easily be bent and routed inside the spacecraft. Furthermore, high pressure fluids such as ammonia require thick-walled container to withstand the high operating pressure and are more hazardous to humans in human space programs. For thermal management of small electronics with heat dissipation in the above range, there is scope for alternate working fluids that are less hazardous. Thus, issues related to design, miniaturization of the heat transport devices and use of working fluids that are less hazardous are still open for research. Secondly, the operating characteristics of an LHP are strongly influenced by the flow and heat transfer characteristics in the wick which need to be explored in detail. Thus, the present research focuses on the investigation of an LHP with a flat evaporator with various working fluids – acetone, methanol, n-pentane and ethanol.

An LHP with a flat evaporator has been built and tested with acetone, methanol, n-pentane and ethanol for heat inputs starting from 25 W till deprime for two coolant set points (-20 °C and 0 °C). The LHP is also provided with a visualization arrangement to observe the phenomena occurring inside the compensation chamber (CC). Experimental results reveal that methanol has the highest deprime limit, followed by acetone, ethanol and n-pentane in decreasing order. It was also found that n-pentane has the lowest operating temperature followed by acetone, methanol and ethanol in increasing order. It was observed that increase in the sink temperature causes an increase in the operating temperature, a decrease in the deprime limit and a decrease in the total thermal resistance offered by the LHP to the heat transport from the evaporator to the sink. Visualization studies reveal that the LHP operates without any nucleation in the CC for all the heat inputs till deprime. However, the deprime of the LHP is characterised by intense nucleation inside the CC, an increase in the operating temperature and a decrease in the condenser exit

temperature indicating ceasing of the fluid flow inside the LHP. Since the LHP evaporator will be directly in contact with the electronic package for its temperature control, the evaporator wall temperature will influence the electronic package temperature and its life. Hence, a model for prediction of the evaporator wall temperature under the assumption that the wick is always saturated with liquid is developed which can serve as a design platform for miniature LHPs for thermal management of electronic packages. The maximum underprediction of the evaporator wall temperature with respect to the measured evaporator wall temperature in the model is found to be 16.4 °C. Based on the results of this model, it is inferred that there exists a vapour blanket in the wick causing an additional resistance for the heat flow from the evaporator to the working fluid for its vapourization and another model is developed to estimate the vapour blanket thickness.

By balancing the loop pressure drop with the capillary pressure, an equivalent apparent contact angle which is a measure of wettability of a working fluid is estimated on a relative scale for each working fluid. It was found that ethanol has the highest wetting, followed by methanol, acetone, and n-pentane in decreasing order, or the lowest contact angle, followed by methanol, acetone, and n-pentane in increasing order. It was also found that fluid with less wetting recedes faster into the wick.

The impact of the location of liquid-vapour interface on the evaporative heat transfer coefficient is studied for all the fluids. It was found that decrease in the evaporative heat transfer coefficient is mainly due to increase in the vapour blanket thickness in the wick.

In order to compare different working fluids with respect to their operating characteristics, an improved LHP figure of merit with a correction factor is presented. This figure of merit clearly distinguishes the operating temperatures of a given LHP with different working fluids and is superior to other figures of merit available in literature. The proposed figure of merit can serve as a predictive tool for making qualitative assessment of the operating characteristics of an LHP.