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MANUFACTURING OF A COST-EFFECTIVE FLAT COPPER WATER LOOP HEAT PIPE

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1 ABSTRACT

This paper presents the development of a novel copper-water flat evaporator loop heat pipe (fLHP) model with compact evaporator dimensions of 60x40x5 mm for electric car batteries thermal management. The fLHP can operate both with and against gravity, transporting up to 250 W (25.6 W/cm^2) when aided by gravity and 120 W (12.3 W/cm^2) when operating against gravity. The maximum transport distance tested was 1.5 m. An optimised filling ratio of 4.5ml was determined which minimised the overall thermal resistance of the fLHP (0.116 K/W).

KEY WORDS: Electronics cooling; Loop Heat Pipe; High flux cooling;

2 INTRODUCTION

A flat loop heat pipe (fLHP) is a highly efficient heat transfer technology. It works on a closed evaporation and condensation cycle by using "the capillary mechanism" for pumping the working fluid. A basic fLHP contains a capillary structure (wick) and acts as a capillary pump and an evaporative heat exchanger, a compensation chamber attached to an evaporator which serves for accumulating the working fluid during the operation of the fLHP [1], a condenser which is connected to the evaporator by separate smooth-walled pipes for liquid and vapor flow. Management of heat dissipation needs of modern electronics has become critical because they are more powerful in terms of processing data etc, hence they generate more heat [2]. Becker et al [3] mentioned in a study that heat flux dissipation in aircraft Seat Electronic Boxes (SEB) installed under each passenger seat might reach up to 100 W (6.25 W/cm^2) in the next couple of years. Ji Li et al [4] stated that heat pipes and other heat transfer technologies cannot meet the high heat dissipation needs of electronics unless major changes in the design of these devices are made, for example adding additional heat sink surface area, increasing the fan speed, or improving the thermal conductance of the heat sink. These technologies will still experience significant issues such as, heavier mass, excess noise and heat pipes will struggle to work with high-power dissipation applications due to its sonic limit. Singh et al [5] had published the experiment results of a fLHP and experiment results shows a fLHP can work successfully at a heat flux of 70 W/cm^2. Flat evaporator fLHP have a great design flexibility and thermal characteristics that makes fLHP an ideal heat dissipation device for future electronics. Some major challenges those holding this technology back such as reverse flow of vapour, ballooning of flat surfaces, optimum wick shape, difficult to start at low powers etc. This study has investigated the different concept design of flat evaporator casing to overcome the fLHP technology challenges.

3 METHODOLOGY

3.1 Flat evaporator casing development

The flat evaporator is a vital part of the fLHP system, and it must be designed well. An evaporator consists of compensation, evaporation, and vapour regions. The compensation chamber feeds the working fluid to

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evaporation region is attached to the evaporator region on the side or top. A primary wick that generates capillary pressure to pump the working fluid in the loop is situated in the evaporator region. Vapour grooves those transport the vapour to the vapour chamber locates on the bottom surface of the evaporator casing or wick structure. A flat evaporator LHP model to work successfully it must satisfy the equation 1.

$$P_{C,max} \geq \Delta P_l + \Delta P_v + \Delta P_w + \Delta P_g + \Delta P_{Channel} + \Delta P_{condenser} \quad (1)$$

This study has investigated different concept designs and parameters of flat evaporator casings to analyse the maximum heat flux it can transport and minimum heat leak to compensation chamber. Novel design features were tried to overcome the reverse flow of the vapour. Ansys Mechanical 2022 was used to analyse the ballooning of the evaporator casing under water saturation pressure of 2.10bar.

3.2 LHP wick sintering process

Primary and secondary wick structure sintering is a major challenge in the fLHP technology. A fLHP wick structure that is not sintered properly to separate the liquid phase from vapour phase will experience the reverse flow of the vapour. Hence the fLHP will not work. The secondary wick plays a vital role to supply the working fluid to the primary wick against the gravity. A novel direct sintering process with novel liquid and vapour core mandrels were used to sinter the primary and secondary wick structure. Success of the direct sintering process in the fLHPs is a great development for the fLHP technology.

3.3 Thermal testing

To use the fLHPs for electronics heat dissipation they must be tested at positive and negative elevation. It should start at low power loads. An optimised fLHP filling ratio is necessary to achieve enhanced thermal performance. Maximum heat transfer length for a fLHP to dissipate the heat successfully.

4 RESULTS

4.1 Novel fLHP model design

The novel flat evaporator fLHP casing is shown in Figure 1. This compact flat evaporator has dimensions of 60x40x5 mm which can transport a heat load of 250 W (25.6 W/cm^2). Novel features were modelled in the evaporator region to avoid the reverse flow of the vapour. Bulkhead walls feature will reduce the heat leak to compensation chamber. An effective vapour chamber area will reduce the pressure drop.

Figure 1: Flat LHP model

4.2 Experimental Thermal Results

The copper water fLHP model successfully dissipated the power load of 250W at +90° Orientation. Maximum Evap-Cond ΔT value was 2.84 ℃ and lowest thermal resistance value of 0.0104 ℃/W was recorded at 250 W shown in the Figure 2. This model dissipated a maximum power load of 120W while working against the gravity. Maximum Evap-Cond ΔT(℃) value of 13.10°C was recorded at power load of 120W and lowest thermal resistance value of 0.074 ℃/W was achieved at 75W of power load shown in the Figure 3. A optimised fLHP model filling ratio of 4.5 was determined experimentally shown in the Figure 4.

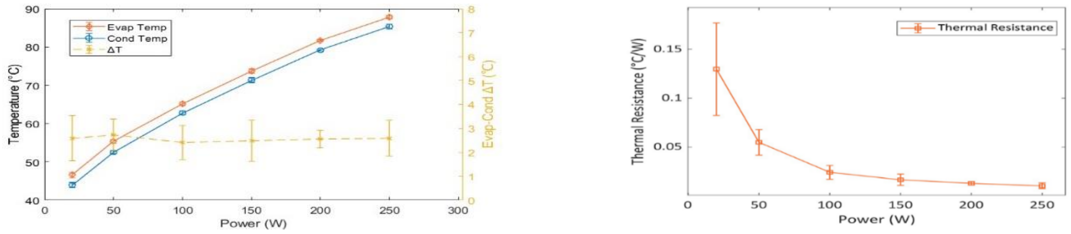

Figure 2: Power test at positive elevation

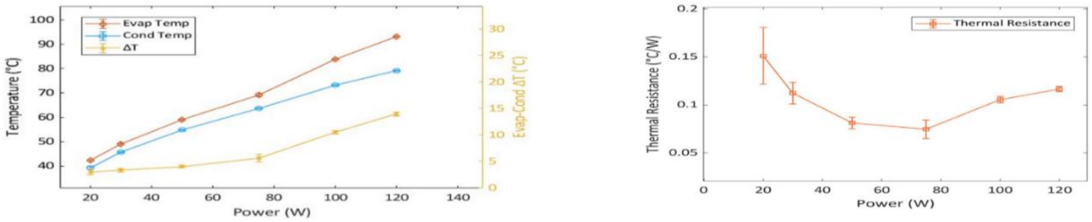

Figure 3: Power test at negative elevation

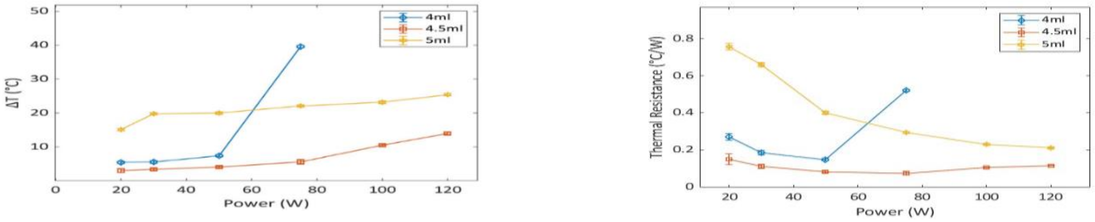

Figure 4: Optimized LHP filling ratio

5 CONCLUSION

Successfully developed a novel flat evaporator fLHP casing design to overcome the fLHP technology challenges of ballooning, vapour reverse flow, heat leak, and primary wick sintering. The fLHP model experimental results show it works successfully at +90° (with gravity) and -90° (against gravity) orientation. The fLHP model dissipates a power load of up to 250 W at +90° orientation. The maximum Evap-Cond ΔT values are between 2°C to 3°C at this orientation. A low thermal resistance value of 0.0104 °C/W was achieved at 250 W at +90° orientation. The fLHP successfully works against gravity and dissipates a power load of up to 120 W, with a maximum Evap-Cond ΔT of 5 °C to 13 °C. The maximum heat transfer length tested was 1500 mm with power load up to 250 W. This LHP model has potential to solve the electric car batteries thermal management needs where they need to dissipate the lengths to 1500 mm. An additive manufactured LHP model will be developed based on this concept which will reduce the fLHP manufacturing cost further. The fLHP model experienced a dry-out at 80°C while working against the gravity this will be investigated in the future with a wick structure with enhanced characteristics.

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