IOP Conference Series: Earth and Environmental Science



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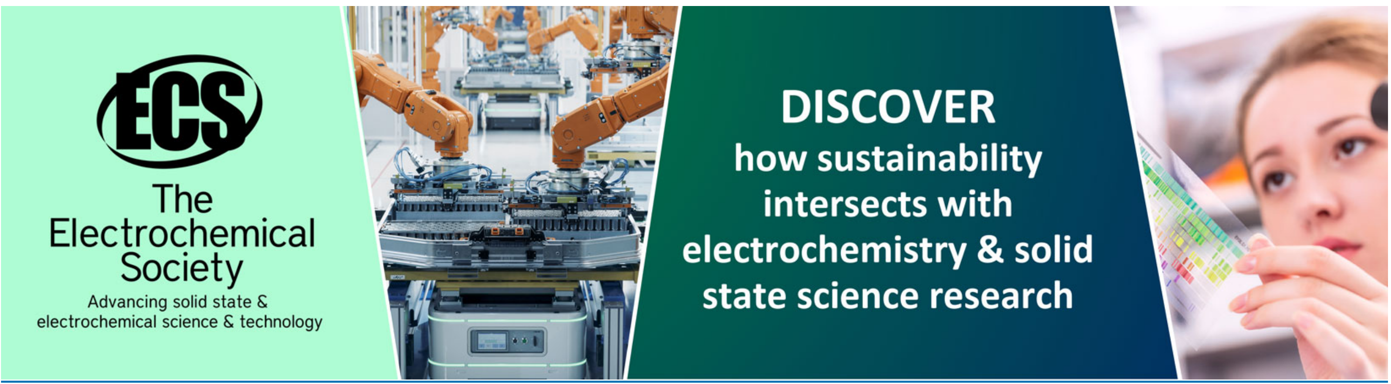
To cite this article: Iwan Setyawan *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **105** 012011





IOP Conf. Series: Earth and Environmental Science **105** (2018) 012011 doi:10.1088/1755-1315/105/1/012011

# Experimental study of hybrid loop heat pipe using pump assistance for high heat flux system

**Iwan Setyawan**[1], **Nandy Putra**[1,2], **Imansyah Ibnu Hakim**[1]
[1]Applied Heat Transfer Research Group, Department of Mechanical Engineering, University of Indonesia, 16424 Depok, Jawa Barat, Indonesia

[2]E-mail: nandyputra@eng.ui.ac.id

**Abstract.** Loop heat pipe is a promising thermal control system, the same as a heat pipe, to realize the efficient release of heat from electric appliances. It is suitable for applications in electronics that have higher power density. Meanwhile, the heat pipe loop (LHP) can also be considered for adoption in the manufacture of solar hot water systems, due to its unique features such as effective thermal conductance and flexible design embodiments. However, the start-up problem of the LHP and transport distance and higher heat release capacity is still existed influencing the operating stability of the device. Base on the problem, this study focuses to carry out work on the developing a novel LHP system in order to provide a robust solution for significant enhance the ability energy transfer. This novel LHP is a conventional LHP that was modified by adding a diaphragm pump to accelerate the fluid transportation (called as hybrid loop heat pipe, HLHP). The pump is installed on the liquid line complete with a reservoir. It will work passively using the wick capillary pressure when there is no sign the occurrence of dry-out. In another hand, the pump was only activated when the evaporator temperature tends increased extremely because of the failure of start-up. The experimental result showed that installed diaphragm pump in LHP modified system was able to prevent the occurrence of dry-out and significantly reduced the evaporator temperature. This study will contribute to energy savings and the utilization of renewable energy.

## 1. Introduction
Two-phase cooling technology passive systems have been widely used and continue to be developed include heat pipes, loop heat pipe (LHP) and capillary pumped loop (CPL). They are very reliable and have very high thermal conductivity [1]. However the two-phase cooling technology passive system occasionally can no longer meet the cooling needs due to inherent limitations in terms of capillary pumping heat flux, the transport distance and the ability to handle multiple heat sources simultaneously. The above-mentioned problem solving is expected to be accomplished along with the successful testing of the use of mechanical pumps into the exhaust heat system of NASA's Rover Exploration Mars, which sparked the current technical trend with the increasing use of active cooling designs for aerospace applications [2]. This cooling system is known as a hybrid loop cooling system that combines pumping of the active mechanical fluid by pumping the capillary liquid. Thus, a hybrid two-phase loop (hybrid) combines high flux capabilities of mechanical pumps and strong pumping operations from conventional

two-phase loops with the simplicity of capillary mechanisms[1, 3]. Moreover, hybrid systems, no longer limited to aerospace applications, but also have been investigated for other applications. Up to now, several experimental studies of hybrid loop cooling systems have been conducted. For example, Park et al [1, 2, 4-6] investigated a loop hybrid system capable of removing the heat of five sources, transient heat flux in the range of heat flux 188 W/cm2 to 250 W/ cm2 and conducted experiment of advanced technology hybrid two-phase loop for thermal management of electronics. Other researchers, Sarraf et al. [3] have demonstrated Hybrid Capillary Pumped Loop for high temperature electronics. Jiang et al. [7] investigated a two-phase loop called pump-assisted capillary loop phase change that is designed to overcome the weaknesses of the temperature oscillations and limited range of heat transfer in the loop heat pipe. Their research carries out the significant advance of the state-of-the-art in hybrid loop heat pipes.

Thus, it is clear that the heat pipe fails to function because the capillary wick is no longer able to restore the liquid to the evaporator, then the evaporator reaches the driest point that causes excess heat and eventually happen dry out [8]. Based on that problem on the heat pipes, hence in this study will be designed a loop heat pipe which is added the pump mechanism which is called hybrid loop heat pipe. The design is slightly different from the design of other researchers. Where in probe the heat pipe loop serves as passive cooling when the heat load and other incoming parameters do not trigger the dry-out and vice versa in case of dry out, the pump will be activated. Thus the heat pipes will be operate on two different conditions.

## 2. Methodology

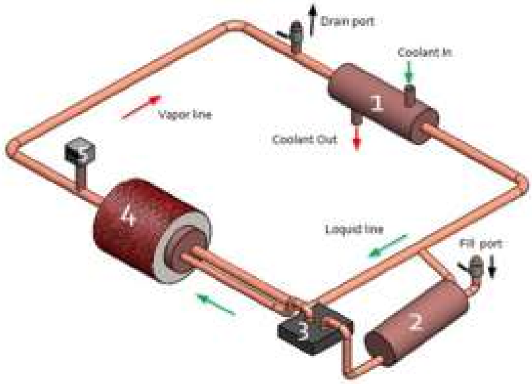
### *2.1. Design and Manufacturing*

LHP are used and designed similar to generally of the loop heat pipes. Evaporator of cylinder model was made of copper pipe to the length of 65mm, an inside diameter of 23mm and a wall thickness of 1.2 mm which merges with the capillary wick, having a thickness of 2mm that was made before. The condenser is also made of copper tubing with dimensions of 70 mm long, 23 mm diameter in counter flow model that has two coolant ports, in and out with diameter of 10 mm. For ensuring the availability of liquid will be pumped when necessary, then this design equipped with a reservoir made of pipes with dimensions of 23 mm in diameter and 65 mm length. In this design the liquid line pipe from the pump made separate directly into the evaporator. As for the total length of the vapor line and liguid line, both equal to 402.5 mm. The addition of a diaphragm pump is used to pump the liquid into the evaporator when needed. With the circulation by this hybrid system, will help the circulation of fluid work on the loop. The more optimal circulation can be given by this mechanism because the pumping system make the fluid circulation better and the speed of the fluid returns to the evaporator faster. The HLHP is displayed a simple configuration in figure 1, which consists of evaporator, condenser, reservoir and diaphragm pump.

Figure 2 shows the experimental setup for testing of the HLHP. In this experiment a heater as a heat source is applied and adjusted by using a DC power supply. Absorbed heat will then be transferred to the condenser through capillarity mechanism and subsequently removed in the condenser and then is absorbed by the water supplied from the Circulating Thermostatic Bath (CTB). In this experiment a micro controller is used to control the diaphragm pump. HLHP used 16 thermocouples, type K that were placed on the main parts. Heat was absorbed by the water coolant, which was at a constant temperature of 25°C and had a flow rate of 100 ml/min supplied from the Circulating Thermostatic Bath (CTB). Furthermore, measured data were recorded using a data acquisition system with NI cDAQ-9174 and NI-9213, which was subsequently processed using Lab VIEW software. The HLHP working pressure during the test was measured using a pressure sensor, PSA-C01, and the NI-9203. To analyze the thermal performance of the HLHP properly, the system had to be perfectly sealed with an insulating material to prevent heat loss to the surrounding environment[9]. In this experiment, is done by varying the heat applied to the evaporator ie starting from 10W continued 20 W, 30 W, 50 W, 90 W, 140 W, 150 W, 160 W, 170 W, 180 W and 200 W. The thermal resistance $R_{th}$ on the loop can be determined using:

$$R_{th} = \frac{T_e - T_c}{Q_{in}} \quad (1)$$

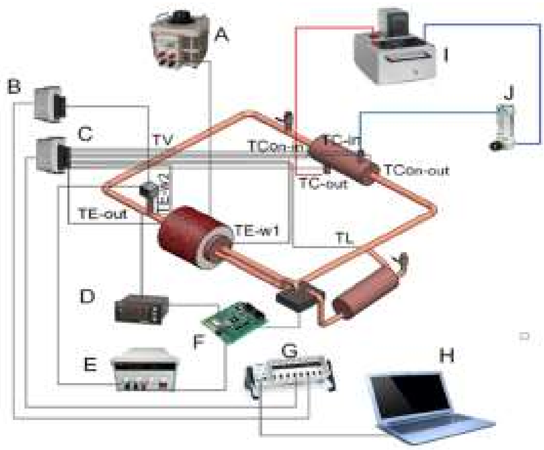
where, $T_e$ is the evaporator temperature, $T_c$ is the condenser temperature.




1 : Condenser
2 : Reservoir
3: Diaphragmpump
4 : Evaporator
5 : Pressure sensor

**Figure 1.** Design of Hybrid loop Heat pipe[9]

*2.2. Test Setup*

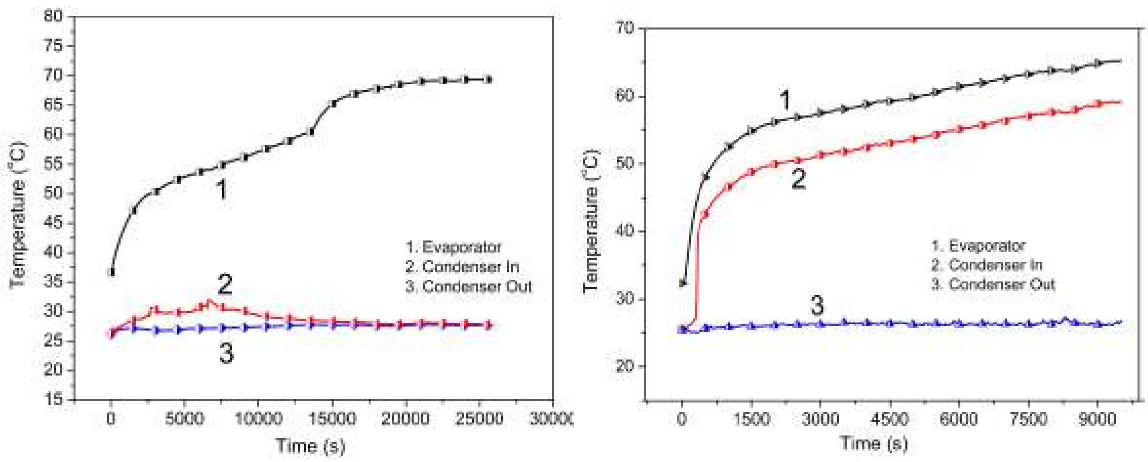



A: AC power supply
B: NI 9203 data acquisition module
C : NI 9213 data acquisition module
D: Temperature controller
E: DC power supply
F : Microcontroller
G: NI Cdaq-9174 chassis
H: Computer
I : Circulating Thermostatic Batch(CTB)
J: Flow meter
H: Computer

**Figure 2.** Schematic installation of hybrid loop heat pipe.

## 3. Result and discussion

Figure 3(a) showed temperature distribution of HLHP when the heat load of 10 W is applied to the evaporator. However, the start-up had not been reached. No forward flow in the system was identified, where the temperature at the condenser inlet was much lower than the saturation temperature in the evaporator[10, 11]. According to some authors, which are based on their own experimental experience, a start-up at low heat loads is a problematic operating mode for LHP. The problem here is interrelated with the fact that at low heat loads a start-up does not take place i.e there is no circulation of the working fluid According to experimental experience by some researchers, start up on low heat load is a problematic mode of operation for LHP. Where here is related to the fact that start up does not occur, ie there is no working fluid circulation at low heat load[12]. Figure 3(b) showed the start-up of the HLHP at a heat load of 30 W. Because start-up was successfully achieved at a heat load of 30 W, it caused a decrease of the evaporator temperature. This temperature was even lower than for the heat load of 10W, where the start-up was not reached.




**(a)** **(b)**

**Figure 3.** Temperature distribution on the HLHP with heat load

(a). 10 W ; (b). 30 W

As already mentioned earlier that under 30W heat load, HLHP start-up successfully. Furthermore, the heat load was raised to 50W, 90W and 140W. From the test result, it found that 140W is the maximum heat load limit that can be handled by HLHP without the help of the pump. Fig 5. showed evaporator temperature and thermal resistance at various heat loads for working of HLHP passively. In the graph, it can be seen when the heat load 10W is raised to 20W, then the evaporator temperature increases. However, when the heat is raised to 30W, the evaporator temperature is precisely much decreased. Furthermore, by more increasing the heat load it will more increase the evaporator temperature. Similarly, when the heat load is increased to 30 W, the thermal resistance is greatly reduced. Figure 4 confirmed the previous discussion in figure 3, that when the 30W heat load is applied, the HLHP is successful start-up where the two-phase system heat transfer becomes dominant.

Figure 5 shows the results with a heat load of 150 W. Under this condition, more vapor formed in the evaporator chamber, will cause overheating on the surface of evaporator. Therefore, the system did not function properly. Heat was absorbed in the evaporator, and it seems that the condenser was no longer able to handle this heat load, as indicated by the temperature oscillation at the condenser outlet. This temperature oscillation is caused by the vapor carried by the working fluid. When the heat load is applied to the evaporator, the resulting vapor enters the condenser to condense which then blocks the flow inside the condenser [13]. Furthermore, the vapor temperature in the evaporator chamber was superheat caused the temperature drastically increased. This rise continued until the pump was activated when the temperature reached 157°C. At this point, the temperature difference in the evaporator wall and condenser inlet much increased. Actually, this is an early sign of dry-out because the receding liquid in the evaporator [14]. However, once the pump was turned on, the temperature of the evaporator decreased suddenly. Regarding to the pump activating would return successfully to the normal conditions i.e the system worked in two phase.

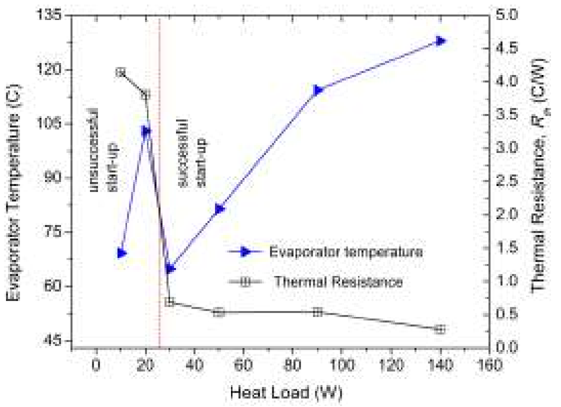



**Figure 4.** The evaporator temperature and thermal resistance versus heat load on the HLHP

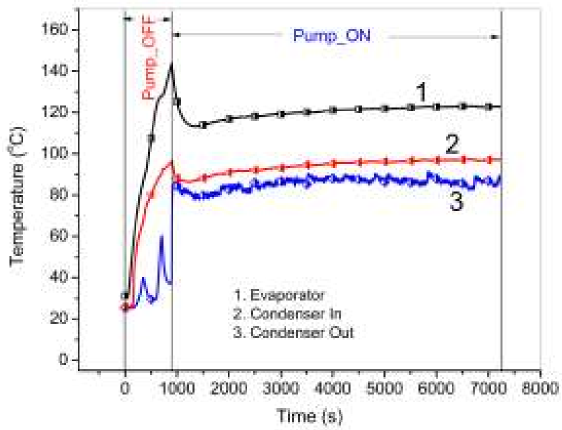



**Figure 5.** Temperature distribution on the HLHP with heat load 150W

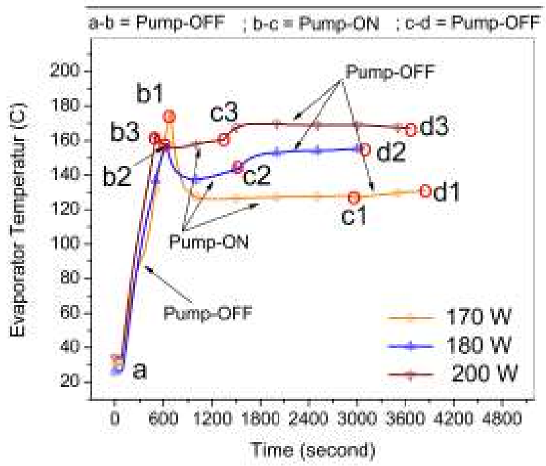



**Figure 6.** The comparison of the evaporator temperature on the HLHP when the pump deactivated and activated

Figure 6 shows the comparison between HLHP when the diaphragm pump is activated (pump ON) and inactive (pump OFF). In the graph, evaporator temperature can be seen at various heat loads applied to HLHP. Furthermore, it can be seen that with the help of the pump, will successfully prevent the occurrence of dry-out and reduce evaporator temperature significantly, especially for heat load 170W. As the heat load increases, the evaporator temperature will rise as well. Nevertheless, the pump remains successful in preventing dry out. Another result is very interesting from the results of this test is the pump turned out just as a trigger to restore HLHP work well.

## 4. Conclusion

Design, manufacturing, and testing of the hybrid loop heat pipe (HLHP) with the integration of the diaphragm pump on the system have been carried out. HLHP will run passively until 140 W without dry out occurance. However, when 150 W is applied to the evaporator, there are early signs the occurrence of dry-out. With the integration of the diaphragm pump in the system, HLHP will able to restore normal conditions. The diaphragm pump has been successful to avoid the dry-out and reduced the evaporator temperature. Thus, this HLHP can be considered for use on devices with high heat-flux.

**Acknowledgment**

The authors would like to thank DRPM Universitas Indonesia, for funding this research through "Hibah PUPT" scheme.

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