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Experimental study on a hybrid loop heat pipe

Iwan Setyawan*, Imansyah* Ibnu Hakim*, Nandy* Putra*

Applied Heat Transfer Research Group, Department of Mechanical Engineering, Universitas Indonesia, 16424 Jawa Barat, Indonesia

Abstract. A conventional loop heat pipe two-phase heat transfer device of passive system often can no longer meet the challenging cooling needs due to the inherent limitations of the capillary pumping which can lead to dry out. This study aims to create a *loop heat pipe* uses capillary wick copper sintered with centrifugal casting method. The stressing effort to overcome the dry-out by adding a diaphragm pump to accelerate the fluid transportation from the condenser to the evaporator (*hybrid loop heat pipe, HLHP*), where the pump is equipped with a reservoir and both installed on the liquid line. In testing the performance of HLHP also varying the *filling ratio, FR*: 50%, 60%, and 80%. The pump will be activated when the dry-out took place, by the piezo electric diaphragm pump with temperature controller installed in the evaporator that was set to activate the pump to work. From the results of the experimental, the pump successfully prevented the occurrence of dry out, and reduced the temperature of the evaporator from 130^{o}C to 80^{o}C, owing the pump distributed the working fluid from the condenser to the evaporator efficiently. The result indicated the best performance of HLHP was filling ratio, FR of 60%.

1 Intoroduction

Nowadays electronic devices tend to have increasingly higher power densities, that certainly would require a heat transfer large amounts as well to maintain their performance and reliability [1]. Since the high heat flux and large heat dissipation operation, many commercial electronics and military weapon systems require high performance cooling. With the rise of hybrids and electric vehicles, next generation power electronics that are known to reach heat fluxes of 100 W/cm^2 are growing sources needing high-performance cooling. The military has been developing various direct energy weapons such as railguns and high power laser systems requiring large amounts of cooling and high heat flux dissipation that are critical for their efficient operation and likely achievable only by two-phase heat transfer [2]. In this case the heat pipe is expected ideal applied to the devise that demanding high reliability and performance as a two-phase cooling system [3, 4]. As known that the two-phase heat transfer has higher heat transfer than heat transfer using a single-phase sensible heat of fluid. Latent heat of vaporization of water for instance, is two orders greater than sensible heat in the cooling system of one phase of the same size. This makes the two-phase heat transfer is superior in terms of heat transport capacity. In addition, the effect of boiling gives the possibility of increased absorption of heat per unit volume of liquid and boiling also produces heat transfer coefficient is much larger ranged 22,5-100 kW/m^2-K [5-9].

The two-phase cooling technologies used for aerospace applications include *heat pipes, loop heat pipes* (LHP) and *capillary pumped loops* (CPL) which are all passive cooling system, thus very reliable devices relying on only capillary pumping. However, the passive devices could not meet future challenging cooling demand because of the inherent limitation of the capillary pumping in terms of heat flux, transport distance and multiple heat source capabilities [10-12]. Meanwhile, high heat flux in advanced defense devices is found in radars, directed-energy laser and microwave weapon systems, and avionics. These devices follow the trend of escalating power density of commercial electronics, heat fluxes from defense devices are now projected to exceed 1000 W/cm^2. This level of heat dissipation exceeds the capabilities of today's most advanced dielectric liquid cooling systems, single-phase or two-phase, which points to an urgent need to develop new powerful cooling solutions[13]. The limitations of the above seem to be resolved with the successful integration of mechanical pump into the exhaust heat system of the Rover Exploration Mars, NASA which also helped create the current technical trends with increasing use of active cooling design for space applications [10]. This active cooling system is known as a hybrid loop cooling system that combines mechanical pumping liquid active with capillary pumping liquid passive. Thus, a hybrid two-phase loops (HTPL) combines the capabilities of the high heat flux and robust operation of conventional pumping two-phase loop with the simplicity and reliability of the

*Corresponding Address: nandyputra@eng.ui.ac.id

capillary mechanism [7, 14]. Then the hybrid system also has been observed for other applications, no longer confined on the space applications[6, 7, 9, 10, 14-16]. The results of their research represented a significant advance over the state-of-the-art in hybrid loop heat pipes.

Based on the limitation in the two-phase cooling technologies, hence in this study, a loop heat pipe has been designed where is modified with installing a pump mechanism in LHP, that is called *hybrid loop heat pipe, HLHP*. The concept of design is slightly different from other research concepts, which in this study of the loop heat pipe works as passive cooling when the heat and other parameters are entered did not cause the appearance of dry out phenomenon, and if dry out happen, then the pump will be activated. Thus, the HLHP can operate with two different conditions.

2 Methodology

In this study, HLHP is developed by the integrating hybrid method. The study was conducted through several stages namely manufacture of wick capillary, design and manufacture and performance testing of HLHP.

2.1 Manufacturing of the capillary wick

The manufacturing process of the wick, i.e., first of all make preparation the copper powder. Then mixed with a binder, where a mixture ratio is 45wt% binder and 55wt% copper powder. The slurry was then mixed until homogeneous. Furthermore slurry poured into the pipe that will be used as evaporator, where in this study was made of copper pipe with lenght of 65 mm and inner diameter of 23 mm. In order that slurry can cling with thickness evenly on the evaporator, inner wall of the pipe, then the process was continued in stage of centifugal casting, by giving a constant rotation with connecting to the 12 volt DC motor. Then proceed to the final stage, where the product through the sintering process by entering into vacuum furnace with the sintering temperature was set at 800 ° C, the temperature rate was set at 20 ° C / min and the heating time was set for 3 hours.

2.2 Design and manufacture of HLHP

The evaporator is designed in cylinder form and made of copper pipe with 65mm in length, an inside diameter of 23 mm and a wall thickness of 1.2 mm which merges with the capillary wick, having a thickness of 2 mm that was made previous. The condenser is also made of copper tubing with dimensions of 70 mm long, 23 mm in diameter. For ensuring the availability of liquid, that will be pumped if it is needed, HLHP is equipped with a reservoir made of pipes with dimensions of 23 mm in diameter and 65 mm in length. In the mid of liquid line from the condenser is designed, where a straight pipe to the evaporator and a short pipe deflected into the reservoir which then the outlet pipe on the bottom of reservoir connected to the piezoelectric pump (**fig.1**).

The addition of the piezo electric pump was used to pump liquid into the evaporator when required, where the hybrid circulation system is expected to help circulate the working fluid from the condenser to the evaporator .

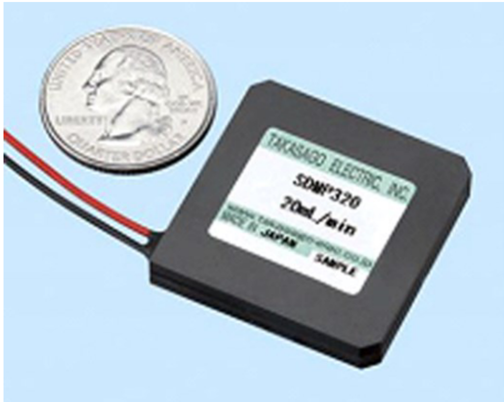
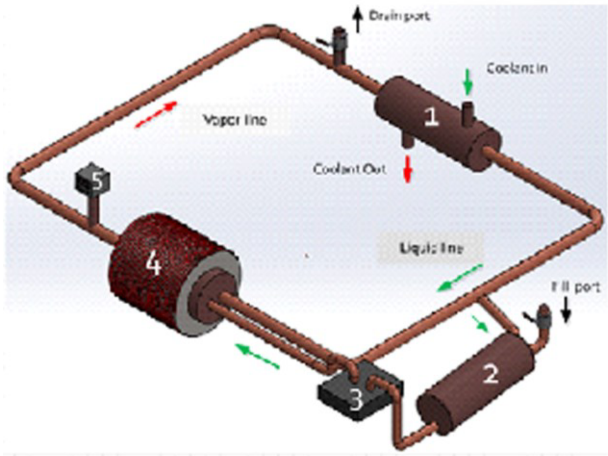


Fig. 1. Piezo electric diaphragm pump



1 : Condenser 4: Evaporator
2 : Reservoir 5: Pressure sensor
3 : Piezo Electric Pump

Fig. 2. Design of hybrid loop heat pipe

The principle of operation of HLHP is depicted in Figure 2. it has evaporator, condenser, reservoir and piezoelectric pump. The liquid reservoir provide enough space to accommodate the liquid to be used when needed. So, the liquid from the condenser flow through the evaporator in two ways: by simply capillary pumping or the combined of capillary pumps and pump piezoelectric.

The manufacture of the evaporator is depicted in Figure 3. The evaporator wick has thicness 2 mm and made from powder copper sintered with 100 µm particle diameter. To prevent the flow of vapor to the liquid line, then at the entrance pipe side of the evaporator inserted a wick with 20 mm lenght that made from the powder copper sintered with 300 µm particle diameter.

In contrast to the loop heat pipe (LHP) conventional works passively, the Hybrid Loop heat pipe (HLHP) which will be made of this, when the conditions in the evaporator reaches the temperature set point, which has been set on the temperature controller, the pump becomes active that will diliver liquid from the reservoir to the evaporator. Thus, the total liquid supplied to the evaporator equal to that produced by the pump plus liquid due to capillary pressure on the wick.

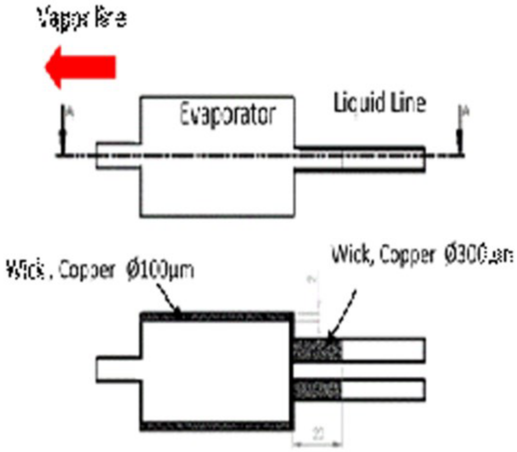


Fig. 3. Design of the HLHP evaporator

2.3 Performance testing of HLHP.

2.3.1 Working fluid filling procedure on HLHP

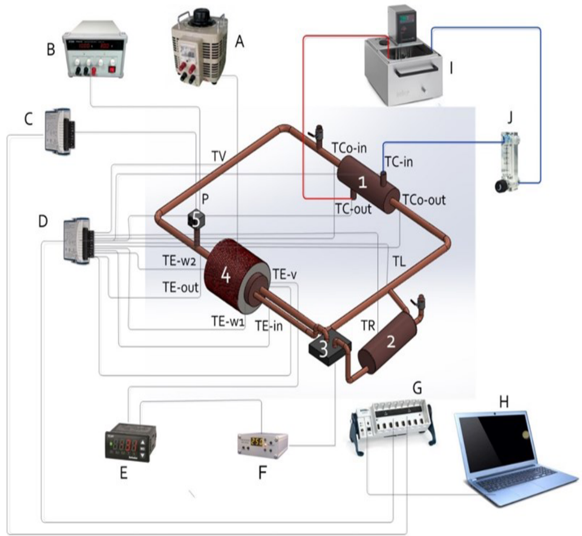
The leakage on HLHP should really be checked at each connection before charging the working fluid. The vacuum pump was used to look for any leaks to as low as -99 kPa which is the limit value of the pump maximum capacity we used. After that, HLHP was left for a few time to ensure no leaks in any part. Then charging the HLHP by filling the distilled water into HLHP through the charging port (fill port) in the reservoir fluid by using an equipment that has been made specifically.

Distilled water was used as the working fluid HLHP with variying the filling ratio (FR) i.e, 50%, 60%, and 80%. The maximum vacuum was done on the HLHP during charging to ensure that there were no non-condensable gases in the system[17].

In the charging process, although it has been done with the maximum effort to avoid the incoming ambient air as well as into HLHP when the charging process, but the amount of air which dissolves in the water can not be avoided, therefore HLHP requires degas procedure before continuing to testing. On the removal procedure of trapped air, the authors followed the method of Park et al. [15], namely operate HLHP with low heating load was enough to make vapor flow in the system. The air is removed from the water, eventually collected in the liquid reservoir. Then the collected gas be withdrawn by a vacuum pump that was connected to the top of the liquid reservoir.

2.3.2 Schematic of performance testing on HLHP

In this expriment, thermocouples K type are installed at some points on the HLHP as shown in the **fig.4.**. Some thermocouples are also mounted on the inlet and outlet of the evaporator, vapor line, inlet and outle condenser, outlet and inlet coolant from CTB, liquid line, and reservoir, then the measured data will be recorded using the NI cDAQ-9174 and NI-9213 which then processed by using Labview software. The HLHP working pressures during the test was measured by using a pressure transmitter PSA-C01, and the NI 9203.



A	: AC power supply	I	: Circulating Thermostatic bath (CTB)
B	: DC power supply	J	: Rotameter
C	: NI- 9203	1	: Condensor
D	: NI- 9213	2	: Reservoir
E	: Themperature Controller	3	: Piezo Electric Pump
F	: Pump Voltage Controller	4	: Evaporator
G	: NI cDAQ- 9174	5	: Pressure control
H	: Computer		

Fig. 4. Schematic of testing on HLHP

3 Results and discussion

In the Figure 5, shows a graph when the experement is conducted at 20W heat load and filling ratio, FR 50%. Form the figure, it can be seen that the boiling condition in the evaporator chamber occurred after 2,500 seconds of operation. It was indicated by the increasing temperature difference between the evaporator wall and its vapor followed by a fall of temperature in the vapor line suddenly. At the same time, temperature at the inlet of the condenser increased, this indicated the increasing of the flowrate of working fluid in HLHP. The steam generated in the evaporator is not sufficient to generate adequate pressure to force the fluid flow more smoothly in HLHP. Since the heat in vapor cannot released in the condenser perfectly, and condesat from condeser is not suficient to supply cooling liquid to the evaporator, it caused the evaporator temperature increaseed rapidly which will lead to dry-out phenomenon. But in this study, dry-out condition has to be prevented by seting the controller to activate the pump before the evaporator temperature reaches 130^{o}C.

In the Figure 5 also presented the phenomenon or temperature distribution on HLHP, when the pump is activated. It can be seen, that the vapor temperature Tv and wall evaporator temperature Te-w decreased drastically after piezoelectric pump is turned on. This is a contrast with rising extrem temperature momentary on the condenser inlet. This phenomenon was probably caused by the alternation of the status of two-phase flow due to the vapor-liquid fluid from the pump supply which suddenly actived is resulting in instantaneous evaporator temperature drops drastically. With the volume of the evaporator mostly liquid will stop the evaporation and furthermore the supply of fluid from the pump will force the working fluid circulation which causes the temperature dramatically increased momentary to whole HLHP except evaporator section. After a certain time of turning on the pump, the temperature on the evaporator reduced into stable condition at 80 ° C .

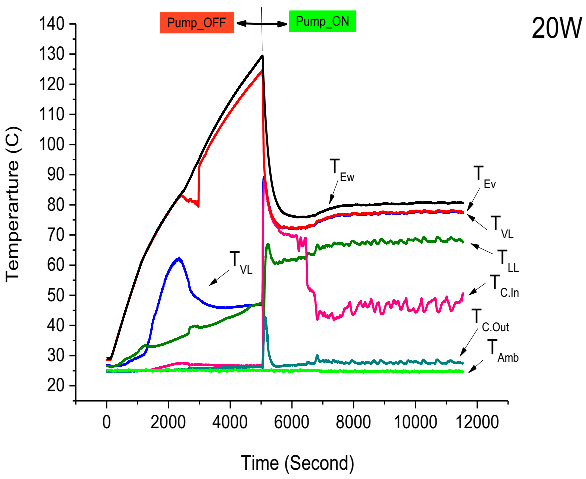


Fig. 5. HLHP experimental result, test at 20W

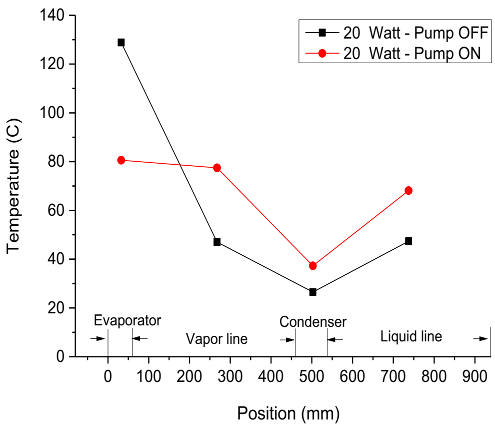


Fig.6. Temperature distribution on the HLHP, test at 20W with pump in active and inactive condition.

In the Figure 6, shows the temperature distribution in HLHP with a heat load on the evaporator 20W with pump in active and inactive condition. It is clear that HLHP can reduce the temperature of the evaporator and can prevent the LHP from the occurance of dry-out conditon.

In the Figure 7, shows the temperature distribution in HLHP, with 60W heat load on the evaporator by varying the filling ratio, FR 50%, 60% and 80%. In the figure can be seen, that for all cases when it reached steady state condition, the temperature distribution has the same trend, the temperature decreased when it entered the vapor line and then through the condenser and to the liquid line except in cases FR 50% when the pump was activated, after exit condenser the temperature slightly increases when entering the liquid line.

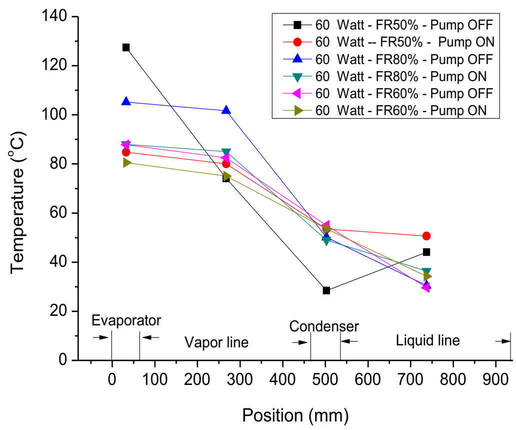


Fig.7. Temperature distribution on the HLHP, test at 60W with pump in active and inactive condition (Filling ratio, FR: 50%, 60%, and 80%).

Furthermore, it can be seen, when the pump inactive, the temperature of the HLHP with FR 60% and FR 80%, HLHP successfully achieved steady state when the evaporator temperature about 88ºC and 105ºC for FR 60 % and FR 80% respectively. On the graph can be seen the condition with the FR 50% after pump is switched on, the evaporator temperature successfully decreased from 130ºC to be steady at 82ºC or 48ºC temperature difference. However with FR 60%, when pump in HLHP is activated when temperatur on the evaporator reached 88ºC, after that temperature on the evaporator decreased and reaches constant at 80°C or differences only 8ºC. Similarly, for FR 80% when temperature of evaporator reached 105ºC then pump is turned on, the temperature of evaporator reduce and to be constant at 85ºC or it decreased 20ºC. A possible reason to explain this is by FR FR80% and 60% although pump has not been activated but HLHP already operated properly.

4 Conclusions

The experiment on HLHP has been conducted with the filling ratio, FR : 50%, 60%, and 80% at heat load 20W and 60W. Instalated piezoelectric pump in modified LHP system was able to prevent the occurance of dry-out in the evaporator. With this system, it will more working fluid flow from condenser to evaporator. From the experiment, the condition of FR 60% has the best performance. The system of HLPH can be considered for the system with high heat flux.

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