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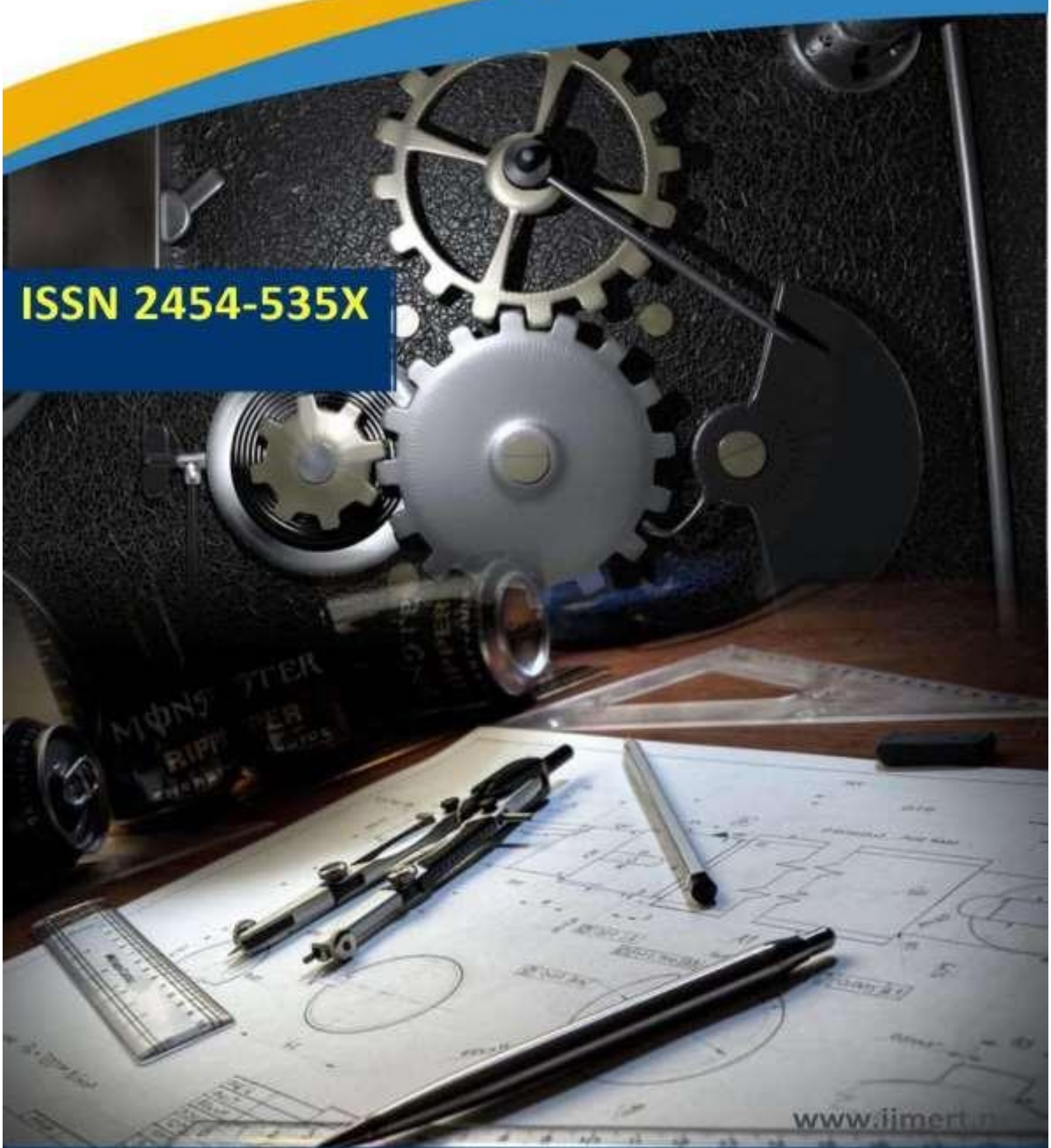

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Experimental Study on Loop Heat Pipe Under Horizontal Condition With Different Working Fluids

Kalyani, Shoba, Swathi , Jyoshna

†Graduate School of Science and Engineering, Saga University 1 Honjo-machi, Saga, 840-8502, Japan

‡Ho Chi Minh City University of Technology – VNU – HCM (HCMUT) 268 Ly Thuong Kiet, Ho Chi Minh City, Vietnam

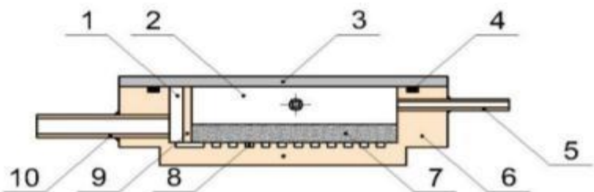
††Department of Mechanical Engineering, Saga University 1 Honjo-machi, Saga, 840-8502, Japan

‡‡International Institute for Carbon-Neutral Energy Research, Kyushu University Nishi-ku, Motooka, Fukuoka, 819-0395, Japan

*Corresponding Author Email: k675@gmail.com

ABSTRACT:

Many scientists and researchers are interested in loop heat pipes (LHPs), which are naturally occurring heat transmission devices that are incredibly flexible and straightforward in their fabrication. Additionally, heat load can be transmitted at rapid rates across long distances with a very tiny temperature drop to demonstrate the usefulness of employing LHP as a heat exchanging device. under this work, the experiment is set up under horizontal situation instead of employing the conventional method of the gravity-assisted orientation. For this process, two different kinds of working fluids have been chosen: water and ethanol. There have already been published experimental results on horizontal orientation with water as the working fluid. It is demonstrated using the current experimental setup that the procedure may be performed over a larger temperature range up to



INTRODUCTION

The quantity of heat produced in such a small area is found to be difficult to dissipate by natural or induced convection, owing to the demand for electrical gadgets with smaller and more compact designs. Nonetheless, since Gerasimov and Maydanik [1-3] established the LHP in 1972, numerous scientists and researchers have been considering the use of LHP as a primary heat transfer method for contemporary electronic equipment. Additionally, a great deal of research has been done to enhance LHP performance and adjust to various working environments. Experiments were conducted by Kaya et al. [4] to investigate low power start-up characteristics with various orientations. According to the authors, the necessary superheat, the highest temperature at startup, and the

Figure 1. Schematic diagram of the previous evaporator 1: vapor collector; 2: compensation chamber; 3: poly carbonate lid;4: O-ring; 5: charging pipe; 6: copper evaporator body; 7: wick; 8: vapor grooves; 9: copper plate; 10: vapor pipe.

EXPERIMENTAL APPARATUS AND DATA REDUCTION

Experimental SetupThe presented setup, which is shown in figure 2, is designed to investigate the performance under horizontal condition, usinga copper-water closed two-phase loop heat pipe, for different heat loads.

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Vol. 7 Issue. 1, Feb 2015

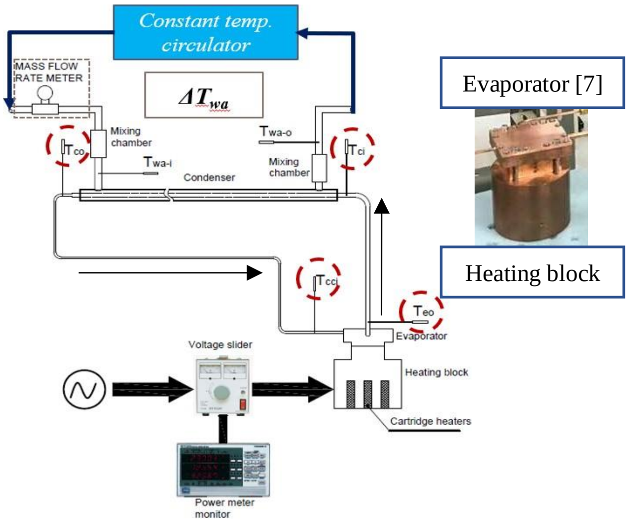


Figure 2. Schematic diagram of experimental setup

The evaporator is heated by four cartridge heaters installed inside the copper heating block. A thin layer of thermal conductivity grease is filled between heater and evaporator surface to minimize thermal contact resistance. Heat load is adjusted by the YAMABISHI MVS – 520 Volt slider and monitored on the YOKOGAWA WT230 digital power meter. On the other hand, the condenser is cooled by water whose inlet temperature is set at 28.5°C by the ADVANTEC LV – 400 constant temperature. The constant low-temperature circulator (ADVENTEC LV -400) designed to provide a continuous supply of cooling water at a constant temperature and volume flow rate was used. From the flow direction of working fluids and cooling water, the condenser used in this loop heat pipe design can be classified as a double-pipe heat exchanger with counterflow arrangement.

To get a better understanding of the loop heat pipe and to determine the heat flux as well as evaporator base body temperature, thermocouples were distributed along the loop heat pipe as follows. Three 0.5mm-diameter K type thermocouples T_1, T_2, T_3 are inserted into the copper heating block and one 1mm-diameter K type T_4 in evaporator base body, as shown in figure 3.

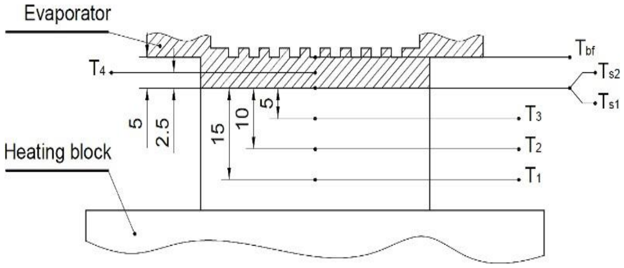
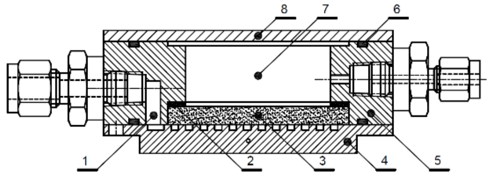


Figure 3. Temperature measurement inside heating block



(A)

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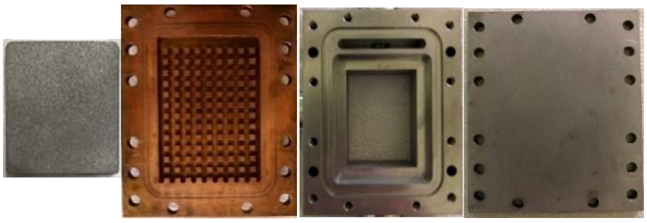
www.ijmert.com
Vol. 7 Issue. 1, Feb 2015



(B) (C) (D) (E)

Figure 4. (A) Evaporator structure: vapor collector (1), silicone gasket (2), SS wick (3), copper base (4), SS body (5), O-ring (6), compensation chamber (7), SS lid (8); (B) Stainless steel sintered wick; (C) copper base of evaporator; (D) SS body; (E) SS lid

The temperature at the outlet of evaporator T_{eo}, inlet and outlet of condenser T_{ci}, T_{co} and inlet of compensation chamber T_{cci} are measured by four K type thermocouples inserted directly on the path of working fluid. Moreover, mass flow rate and temperature of cooling water at inlet and outlet are measured by MASSMAX MMM7150K mass flowmeters and two K type thermocouples. The experiment was carried out in the room with an air conditioner, and a control system was built. During the operation, room temperature is kept at 25 °C and observed by another K type thermocouple T_a. Except for the thermocouple T_a, all thermocouples are calibrated to sure that the uncertainty is ±0.05 °C. A data acquisition system (Keithley 2071) was used to record the temperature measured throughout the experiment at a sampling rate of one data point per second for later analysis. The evaporator has the flat-rectangular shape to cool the electronics devices like processors as described in figure 4, which can contact well with the electronics surface. The evaporator consists of three main parts that are stainless-steel (SS) lid (8), copper base (4) and SS body (5), and the detailed specifications of the test loop are listed in table 1.

Table 1. The main parameters of LHP

Heating block	Copper
Mass, kg	4.36
Evaporator base	Copper
Length x Width x Height, mm	80 x 70 x 8
Active area, mm^2	60 x 45
Evaporator body	Stainless steel
Length x Width x Height, mm	80 x 70 x 23
Fin geometry	
Cross area, mm^2	2 x 2
Height, mm	1.5
Fin pitch, mm	4
Wick structure [11-12]	Stainless steel
Opening, μm	63

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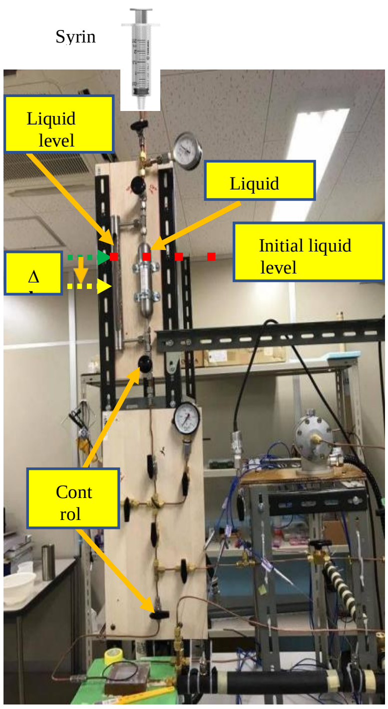
ISSN 2454 – 535X
www.ijmert.com
Vol. 7 Issue. 1, Feb 2015

Void ratio, %	42
Bulk volume, mm^3	50 x 41 x 5
Compensation chamber	
Length x Width x Height, mm	40 x 31 x 18
Vapor line	Copper
OD/ID, mm	6.35/4.35
Length, mm	450
Condenser line	Copper
OD/ID, mm	6.35/4.35
Length, mm	300
Liquid line	Copper
OD/ID, mm	3.2/1.7
Length, mm	950
Working fluid amount (ml)	
Ethanol	31
Water	31

Experimental Condition and Charging System

During the experiment, the evaporator, the copper heating block, the condenser, the vapor and liquid transport lines were insulated. An array of fins or vapor crossing groove system was machined on the evaporator base to create the paths for vapor flow out evaporator as in figure 4, (C). With this design, no need to apply the unique fabricating technology to make the grooves on wick surface, but it promises enough space for evaporation, prevents vapor pocket forming inside the wicked body. The charging system in this experiment consists of a liquid stored tank, a liquid level indicator made of glass, control valves and a syringe, as shown in figure 5.

Firstly, mount the loop heat pipe to the charging system that is equipped with a high vacuum pump and evacuate the loop heat pipe from the non-condensable gases for 24 hours or until the vacuum pressure inside the system to remain constant. Secondly, introduce the working fluid charge into the charging system by using the syringe manually. In the second step, the loop heat pipe was disconnected by the control valve from the charging system.



ISSN 2454 – 535X
www.ijmert.com
Vol. 7 Issue. 1, Feb 2015

Figure 5. Photograph of experimental charging system

During this process, the vacuum condition of the charging system was lost; therefore, two experiments were run to determine the lowest pressure attainable. The first experiment was run using the vacuum pump only. The second experiment used a heat gun at various intervals to accelerate the removal of vapor. Finally, the control valves were used to add the working fluid into the loop heat pipe system, and the quantity of charged working fluid was determined from the liquid level indicator Δh. Moreover, the amount of the working fluid to charge the loop heat pipe was established by the following equations [13],

$$M = \rho_{l,h}[V_{liq} + V_{pw} + V_{sw} + (1-\alpha)V_{cc}] + \rho_{v,h}(V_{gr} + V_{vap} + V_{con} + \alpha V_{cc}) \quad (1)$$

$$V_{pw} = Porosity \times V_{t,w} \quad (2)$$

$$\alpha = \frac{V_{v,cc}}{V_{cc}} \quad (3)$$

$$\Delta h = \frac{V_{lc}}{\frac{\pi D^2}{4}} \quad (4)$$

$$V_{lc} = \frac{M}{\rho_{lc}} \quad (5)$$

In this experiment, the parameter of α was set at 0.1, and the value of V_{sw} is neglected. Besides, the reference point of Δh is considered at the point which has the maximum diameter of the liquid tank. The purified water was also boiled and reduce the concentration of dissolved gases inside its volume before charged into the charging system. REFPROP 10.0 provided by NIST was used to obtain the density data. The temperature dependence of liquid and vapor density of water was considered in the calculation. By using the Pt100 thermometer (Chino Co. Model-R900-F25AT) as a standard source, measurement device uncertainties are listed in table 2.

Table 2. Uncertainty values of measurement devices

T_1, T_2, T_3	±0.06°C
T_4	±0.07°C
T_{eo}	±0.06°C
T_{co}, T_{cci}	±0.1°C
T_{wa-i}	±0.1°C
T_{wa-o}	±0.06°C
Mass flow meter	0.18% of reading

Data Reduction

The values of heat load Q and heat flux q flowing from the heating surface to the active area A (2700 mm^2) of evaporator were calculated by the following equations.

$$q = \frac{1}{}\left(k\frac{T1-T2}{} + k\frac{T2-T3}{} + k\frac{T1-T3}{}\right)(6)$$

International Journal of Mechanical Engineering Research and Technology
ISSN 2454 – 535X
www.ijmert.com
Vol. 7 Issue. 1, Feb 2015

Where, δ = 5mm.3δδ2δ

Q = q*A(7)

And the temperature of the heating block's top surface,

$T_{s1} = {}^{1}[(T_1 - 3\,{}^{q\delta}) + (T_2 - 2\,{}^{q\delta}) + (T_3 - {}^{q\delta}_{t})](8)3k\,R = \frac{T_{s1} - T_{wa-i}Qkk}{(9)}$ —

Then, the total thermal resistance of the LHP can be calculated by the following equation.

RESULTS AND DISCUSSION

This section presents the results of experiments conducted on the LHP for cooling capacity and performance with two working fluids (water and ethanol) for various heat inputs. During the experiments, the condenser inlet temperatures T_{wai} of cooling water were maintained constant.

Operating Characteristics with Water and Ethanol as Working Fluid

The changes in the temperatures such as T_{s1} at the top surface of the heating block, temperatures at different positions in the LHP including T_{eo}, T_{ci}, T_{co}, and T_{cci} on the heating power when the LHP was charged with water and ethanol are demonstrated by following figures 6, 7, and 8. In this experiment, T_{s1} is regarded as the operating temperature of electronics like processors, and it is generally recommended that this temperature should not be higher than 85°C for reliable and safe performance [14].

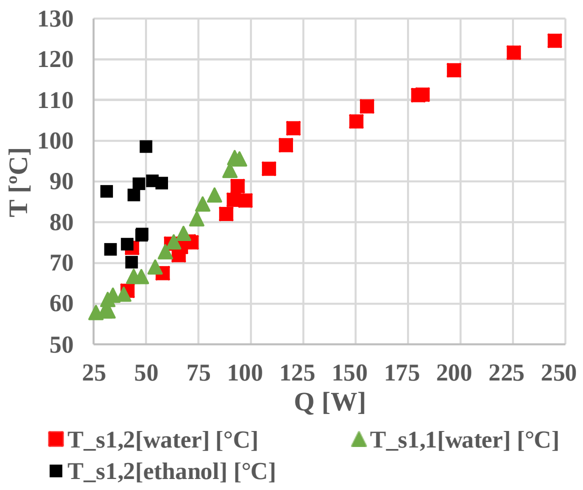
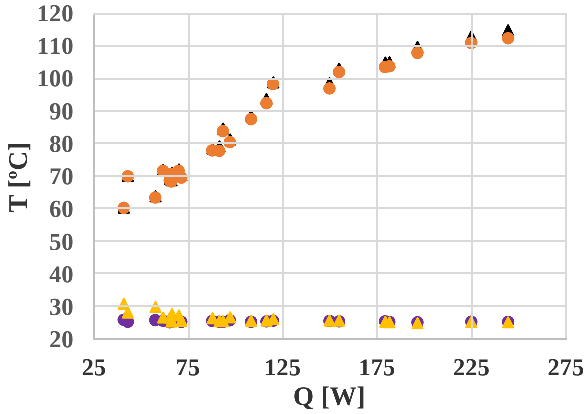


Figure 6. Temperatures T_{s1} varied with heat load, compared with the previous and new design evaporators



ISSN 2454 – 535X
www.ijmert.com
Vol. 7 Issue. 1, Feb 2015

▲ Teo ● Tco ▲ Tcci ● Tci

Figure 7. Temperatures at different locations vs heat load using water as the working fluid, using the new design evaporator

The results in figure 6 showed that the water LHP performed better than ethanol LHP. The water LHP could be operated stably in the range of 41 to 244 W, in which the temperature at the top surface of the heating block raised from 63ºC to 124ºC. In the case of ethanol, the stable operation was limited up to 57W, which is lower than water LHP. If a limited temperature of electronics is recognized at 85ºC at the heater surface, the maximum heat load was 48 W for the ethanol LHP and 88 W for water LHP respectively. Moreover, the water LHP with the new evaporator design achieves the higher heat flux than the previous design of water LHP, while the ethanol LHP with the previous design could not make an operation.

Furthermore, as shown in figures 7 and 8, the temperatures T_{eo} and T_{ci} exist almost at the same values, while T_{co} and T_{cci} are nearly equal together. This result confirms working fluid circulates stably inside the loop for both water LHP and ethanol LHP. However, the ethanol LHP has higher fluctuations than the water LHP in the range of heat load from 31 W to 50 W, where the values of T_{cci} were slightly higher than the values of T_{co}. It means that the vapor-liquid interface near the thermocouple T_{cci} inside the liquid line appeared intermittently, and as a result, the supplying liquid for the compensation chamber could not flow stably. Therefore, the cooling performance of the condenser operating with ethanol was decreased, and the ethanol LHP could not operate as stably as the water LHP.

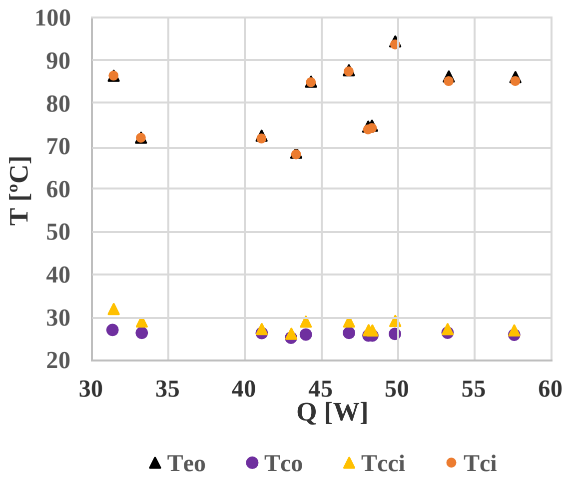


Figure 8. Temperatures at different locations vs heat load using ethanol as working fluid, using the new design evaporator

Changing of Total Thermal Resistance with Heat Load

Figures 9 and 10 present the total thermal resistance of the water LHP and ethanol LHP that are calculated by Eq. (9) and demonstrate that the water LHP operated better than ethanol LHP. In this experiment, the lowest thermal resistance was 0.4 K/W (Q = 244 W) for the water LHP with new evaporator design. In the case of ethanol LHP and water LHP with the previous design, they showed relatively high total thermal resistances such as 1.03 K/W and 0.7 K/W. The total thermal resistance of water LHPwith the new and previous evaporator designs tend to decrease with the increasing heat input. When the supplied heat to the evaporator increased from 43 W to 244 W for the water LHP with the new evaporator design and from 26 W to 94 W for the water LHP with the previous design, the resistances were significantly reduced from 1.11 to 0.4 K/W and from 1.11 to 0.7 K/W for the previous design, respectively.

However, the cooling capacity of ethanol LHP was lower than the water LHP because of the higher thermal resistance existing at the condenser of the ethanol LHP. According to the thermal properties of water and ethanol, water has higher latent heat and liquid thermal conductivity. Therefore, the ethanol liquid condensing layer is thicker than the water at the same condition of heat released from the condenser and this liquid layer could become the resistance to prevent the heat transfer process from the vapor to cooling liquid. Besides, the condenser of water LHP could possess lower thermal resistance because of the low vapor density of water that makes vapor velocity higher. As a result, the total thermal resistance of the ethanol LHP reduced with the increased

International Journal of Mechanical Engineering Research and Technology

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www.ijmert.com
Vol. 7 Issue. 1, Feb 2015

heating power only in the range of heat load from 31 to 43 W.

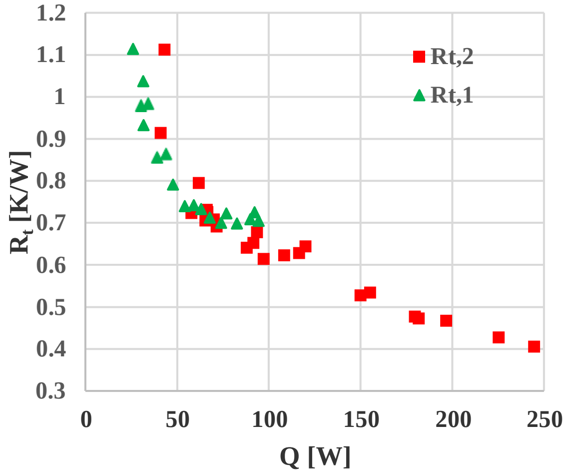

Figure 9. Total thermal resistance of the water LHP with the previous and new design evaporators

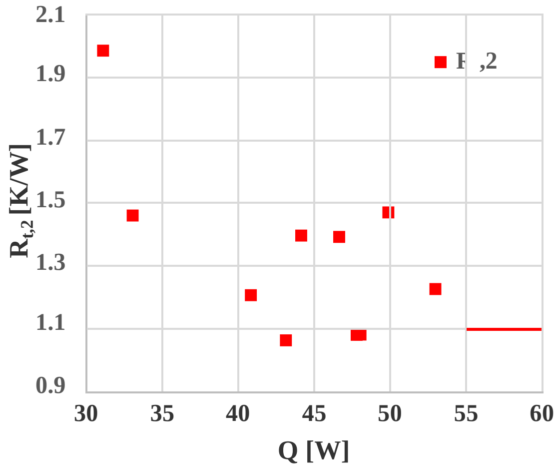

Figure 10. Total thermal resistance of the ethanol LHP with the new design evaporator

CONCLUSION

In this study, the LHP with the flat-rectangular evaporator was fabricated and investigated thermal performance under horizontal orientation with two working fluids (water and ethanol) for various heat inputs. Sintered stainless steel wick was installed inside the evaporator for the capillary pumping of them. The experimental results demonstrate that, the water LHP has better cooling performance than the ethanol LHP. The heater surface temperature of water LHP increased from 63 ºC to 124 ºC in the range of heat load from 41 to 244 W. In the case of ethanol, the stable operation was limited up to 57 W whichis lower than water LHP. The water LHP could maintain the temperature at the top surface of the heating block smaller than 85ºC when operating under heat power of 88 W. However, the ethanol LHP could satisfy this condition when the heat powerwas around 48 W only.

International Journal of Mechanical Engineering Research and Technology

ISSN 2454 – 535X
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