Journal of Engineering and Sustainable Development

Vol. 24 No.02, March 2020
ISSN 2520-0917
https://doi.org/10.31272/jeasd.24.2.2

# EFFECT OF FILL RATIO ON EVAPORATOR WALL TEMPERATURE IN A LOOP THERMOSYPHON USED IN ELECTRONIC COOLING APPLICATIONS

*Samah Ihsan Adnan[1], Dr. Aouf Abdulrahman Ahmad[2], Dr. Adnan Adulamir Abdulrasool[3]

1) M.Sc. Student, Mechanical Engineering Department, Mustansiriyah University, Baghdad, Iarq.
2) Lecturer, Mechanical Engineering Department, Mustansiriyah University, Baghdad, Iarq.
3) Prof., Mechanical Engineering Department, Mustansiriyah University, Baghdad, Iarq.

Received 7/3/2019 Accepted in revised form 25/ 4/2019 Published 1/3/2020

**Abstract:**This paper presents the effect of filling ratio on thermal performance of a loop thermosyphon. The experimental setup consists of an evaporator, a condenser, a riser and a downcomer. The dimensions of the loop thermosyphon under consideration were chosen so that they are mostly suitable for use in the cooling of electronic components. Distilled water was used as a working fluid. Experiments were carried out to estimate the performance of the loop thermosyphon for a range of input power from 10 to 100 W. Four fill ratios were considered in the present work, namely; 15%, 25%, 50% and 85%. Results showed that the maximum value of wall temperature in evaporator was 95°C, at 100 W input power and 15% fill ratio. The fill ratio of 50% gave the minimum evaporator wall temperature which was 80°C. Increasing fill ratio tends to decrease the evaporator wall temperature for evaporator.

**Keywords**: *Loop Heat Pipe, Thermosyphon, Fill Ratio, Saturation Temperature*

## تأثير نسبة الملىء على درجة حرارة المبخر في الثرمسيفون الحلقي المستخدم في تطبيقات التبريد الالكترونية

**الخلاصة:**هذا البحث يعرض تأثير نسية الملىء على الاداء الحراري للثرموسيفون الحلقي. يتكون الإعداد التجريبي من المبخر، المكثف،الانبوب الصاعد والنازل. تم اختيار الأبعاد للثرموسيفون (الانبوب الحراري) بنظر الاعتبار بحيث تكون مناسبة أكثر لأستخدام في تبريد الاجهزة الالكترونية.تم استخدام الماء المقطر مائع التشغيل. تم أجراء اختبار التجارب من اجل تقدير اداء أنواع مختلفة لمجموعة من مدخلات الطاقة من 10واط الى 100واط.واخذت بنظر الاعتبار أربع نسب تعبئة وهي 15%،25%،50%،85%.أظهرت النتائج ان القيمة القصوى لدرجة حرارة جدار المبخر هي 95° عند قدرة 100واط ونسبة الملىء 15%. نسبة الملىء 50% أعطت درجة حرارة دنيا تبلغ 80°. زيادة الحاصلة في نسبة الملىء تؤدي الى نقصان قي درجة حرارة جدار المبخر .

## 1. Introduction

Loop thermosyphon is a two-phase heat transfer device with high thermal conductivity. It is used in many applications such as solar thermal engineering, waste heat recovery, cooling of nuclear reactors and cooling of electrical and electronic components.

**Corresponding Author:* Samahehsanadnan33@gmail.com

Thermal process in this device starts from the evaporator where heat is absorbed from an external source such as a hot bath or electrical heater.

The heat is transferred through the evaporator walls to the working fluid. The saturated working fluid absorbs adequate heat to change from liquid to vapor phases. The amount of heat is proportional to the latent heat of vaporization. The generated vapor moves through an adiabatic section to the condenser where it condenses and rejects heat to a heat sink through the condenser walls. The condensate returns to the evaporator by gravity effect through another adiabatic section completing the loop. The condenser thus, must be placed above the evaporator level [1].

Many researchers worked on loop heat pipes to understand its thermal performance. [2] experimentally studied a rectangular thermosyphon loop. They found that the evaporator and condenser heat transfer coefficients increase with decreasing the loop charge.

[3] investigated the hydrodynamic stability of natural circulation two-phase flows in a loop thermosyphon with tube separator.

[4] studied the effects of fill ratio, mass flow rate and inlet cooling water temperature in the condenser jacket on the performance of a two-phase loop thermo- syphon. They found that the best fill ratio lies between 7% and 10%.

[5] conducted study on a loop heat pipe consisting of an evaporator, a condenser and connecting pipes. The study used mathematical models that were solved via the commercial software; Engineering Equation Solver (EES).

[6] investigated the heat transfer characteristics of a two-phase closed loop thermosyphon. The experiments applied input power in the range between 50 and 600 W. The fill ratio was changed between 10% and 70%. Results showed that increasing the power enhances the heat transfer in the loop.

[7] experimentally studied the performance of a loop thermosyphon. It consisted of an evaporation section and condensation section. The cooling water temperature was varied from 20°C to 50°C for a range of fill ratios from 5% to 50% while the input power ranged between 20 W to 250 W. Water and methanol were employed as working fluids inside the loop. Results showed that the best fill ratio is 30% for water and 10% for methanol.

[8] experimentally studied a loop thermosyphon for cooling of electronic components. Fluorocarbon FC72 was used as a working fluid. They found that the temperature of evaporator did not exceed 80°C.

[9] studied the effect of working fluid to remove heat from an electronic component by using a Loop Heat Pipe (LHP). Results showed that the optimum amount of fill ratio is about 50% to 60%.

[10] Studied the dynamic performance of loop heat pipe for cooling of electronics. In the work the mathematical model has been implemented in MATLAP program. They found that the comparative between the simulated results and the experimental data good agreements have been observed.

It can be concluded from the previous research endeavors that no single optimum value of fill ratio may be ascertained. So, the present work seeks to further investigation to the effect of fill ratio on the thermal performance of a loop thermosyphon (loop heat pipe) that may be used in electronic parts cooling. This will be done through an experimental tests on a real system fabricated for this regard.

## 2. Experimental Setup

Fig.1 shows a schematic diagram of the experimental test rig of the loop thermosyphon under consideration. It consists of an evaporator, a condenser and the connecting pipes. One pipe is the vapor line to carry the generated vapor from the evaporator to the condenser which is called (upriser). The other pipe is the return line of the condensate from the condenser back to the evaporator and is called (downcomer).

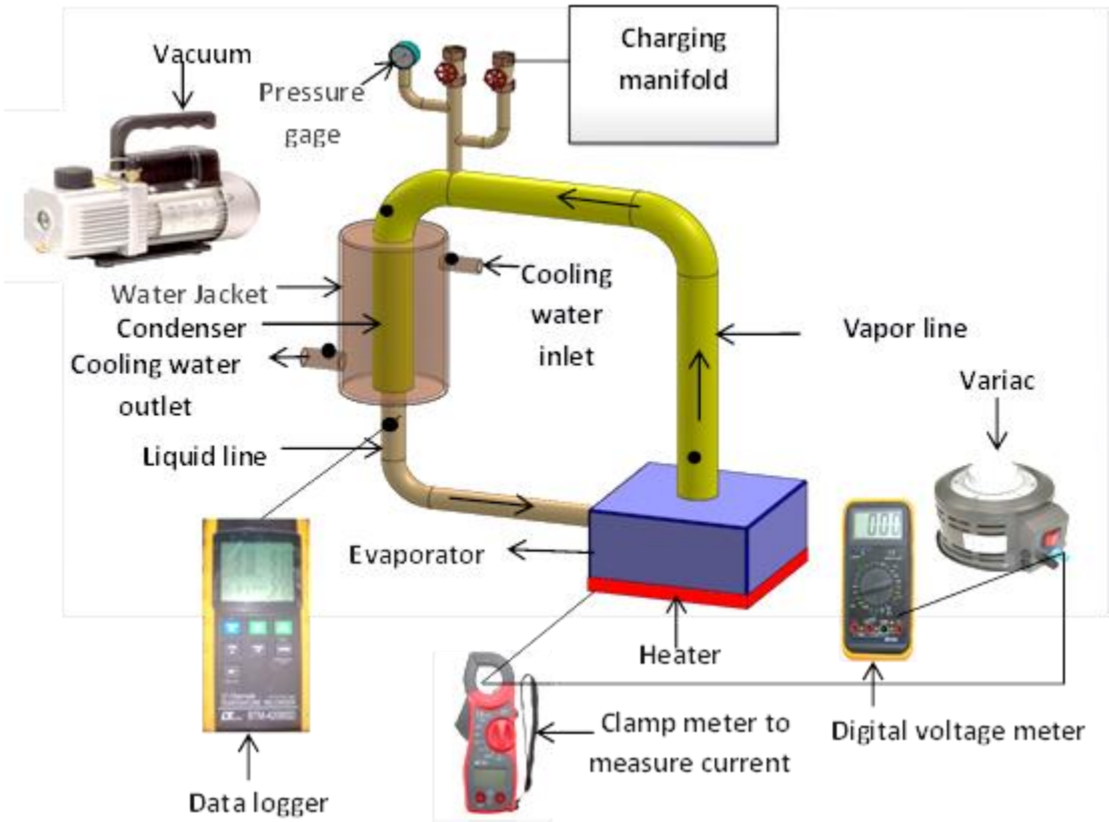



Figure1. Schematic diagram of experimental setup of the loop thermosyphon.

The loop thermosyphon is made of copper to resist corrosion by water. The evaporator is placed on the lower part and the condenser on the upper part of the loop to enable circulation by the gravity effect. The riser and downcomer diameters are 15 mm and 9.5 mm respectively. The evaporator is made as a rectangular copper alloy box of dimensions (100x100x30) mm. The input power is supplied via an electric heater. The heater plate is made of aluminum alloy with 100 mm length and 100 mm width. The heater is firmly attached to the bottom side of the evaporator and tightly insulated at the other side to ensure that all of the supplied power is directed to the evaporator. The condenser is made of a copper cylindrical tube of 15 mm diameter and 150 mm length. The condenser is cooled by a water jacket of 20 mm diameter and 150 mm length.

Polyurethane (foam) is used as an insulating material of the system components to minimize the heat loss to the environment.

An AC electric power source of 220 V supplies power to the heater. The power supplied to the heater can be varied between 0 W to 250 W. All temperature measurements are executed using calibrated K-type thermocouples. Twelve data points for temperature measurements are considered.

Five thermocouples (No.1-5) are attached to the outer surface of the loop thermosyphon to measure the evaporator wall temperature. Thermocouple (No.6) measures evaporator outlet temperature.

Thermocouple (No.7) measures the temperature of the vapor inside the condenser. Two thermocouples (No.8-9) are used to measure temperature of the inlet and outlet of cooling water jacket.

The thermocouples (No.10-11) are used to measure the temperature of the liquid before the evaporator, while the thermocouple (No.12) is used to measure the ambient temperature. Data recorder type (BTM-4208SD) which contains 12 channels is used to monitor and record the temperature for the loop thermosyphon. Fig. 2 shows schematic view of the locations of the thermocouples around the loop thermosyphon.

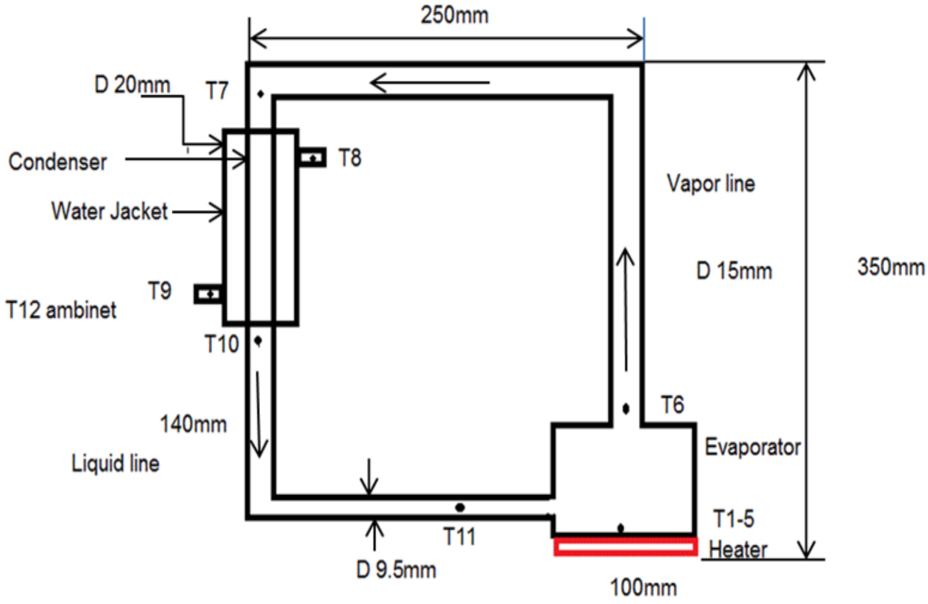



Figure2. Schematic view of the locations of the thermocouples at the loop thermosyphon.

The saturation and vacuum pressures are measured by two devices. One device is a pressure gage and the other device is a digital pressure meter type (Lotron PS-9302). Fig.3 shows the experimental setup of the loop thermosyphon under consideration.

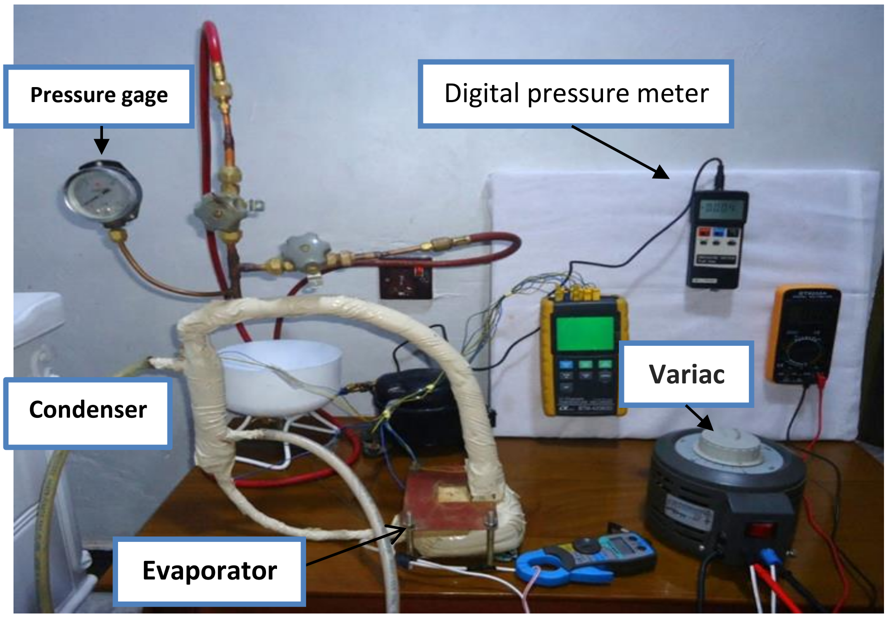



Fig.3 Photo of the experimental setup of the loop thermosyphon under consideration.

## 2. Experimental Procedure

The experimental procedure can be summarized as follows:

1. The loop thermosyphon is evacuated by a vacuum compressor while all the valves are closed. The reachable vacuum pressure is about 8 kPa absolute pressure.
2. The loop is then charged with water as a working fluid. The distilled water is filled through the liquid-level column. The column valve is then opened to allow the water to enter the evacuated space of the heat pipe. The filling valve is then closed as soon as the required amount of the water indicated by the level reading is reached.
3. Heating of the loop is then initiated by turning on the voltage stabilizer and the power supply on the control panel.
4. The data recorder system is turned on and the temperature readings are displayed. Steady state condition is achieved within 15 to 30 minutes after the startup, the condition at which all readings practically unchanged. Experimental readings are then started and the data are recorded.

## 5. Data Analysis

The power input $Q_{in}$ is calculated as voltage V times current I :-

$$Q_{in} = V\,I \qquad (1)$$

The thermal resistance of evaporator $R_{evap}$ is evaluated as the ratio of temperature difference to the power input $Q_{in}$[11]:

$$R_{evap} = \frac{T_w - T_{sat}}{Q_{in}} \qquad (2)$$

The condenser thermal resistance $R_{cond}$ is estimated by the following equation:

$$R_{cond} = \frac{T_V - T_{in}}{Q_{cond}} \quad (3)$$

The condensation heat transfer rate $Q_{cond}$ is calculated from the temperature increase of the cooling water across the water jacket as follows:

$$Q_{cond} = \dot{m}_{w1} cp_{w1} (T_{out} - T_{in}) \quad (4)$$

$$R_{total} = R_{evap} + R_{cond} \quad (5)$$

The evaporation heat transfer coefficient is defined by the following equation [12]:

$$h_e = \frac{Q_{in}}{A\,(T_w - T_{sat})} \quad (6)$$

## 5. Results and Discussion

The fill ratio is an important factor influencing the thermal performance of loop thermosyphon. Fig. 4 shows variation of measured average wall temperature in evaporator for a range of input power starting from 10 W to 100 W at a step of 10 W for fill ratios of 15%, 25%, 50% and 85%. It can be seen from the figure that the wall temperature increases continuously with input power for all fill ratios. Increasing fill ratio tends to decrease the wall temperature because of the enhanced evaporation rate. The fill ratio of 50% shows the best cooling effect at which the wall temperature reaches its minimum value of 80°C. Fig. 5 shows experimental variation of measured wall, evaporator inlet and outlet temperatures and saturation temperature with evaporator input power at a fill ratio of 50%.

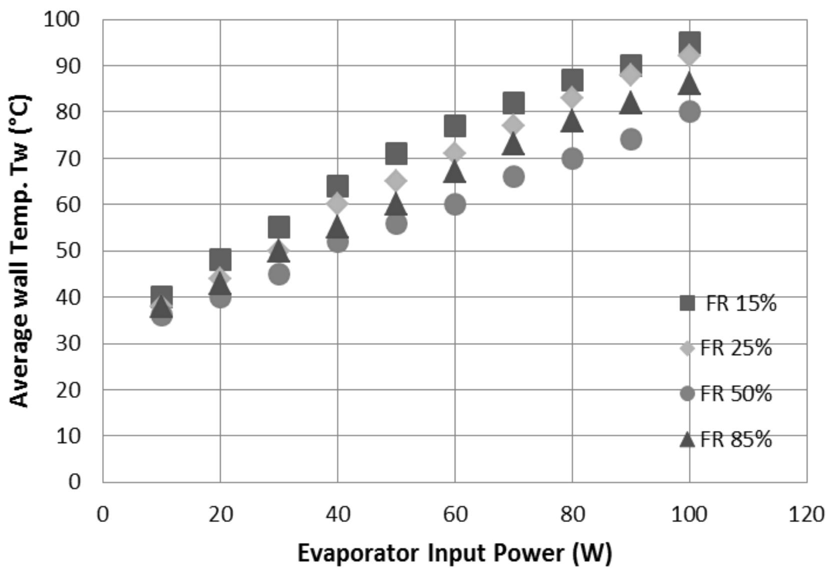
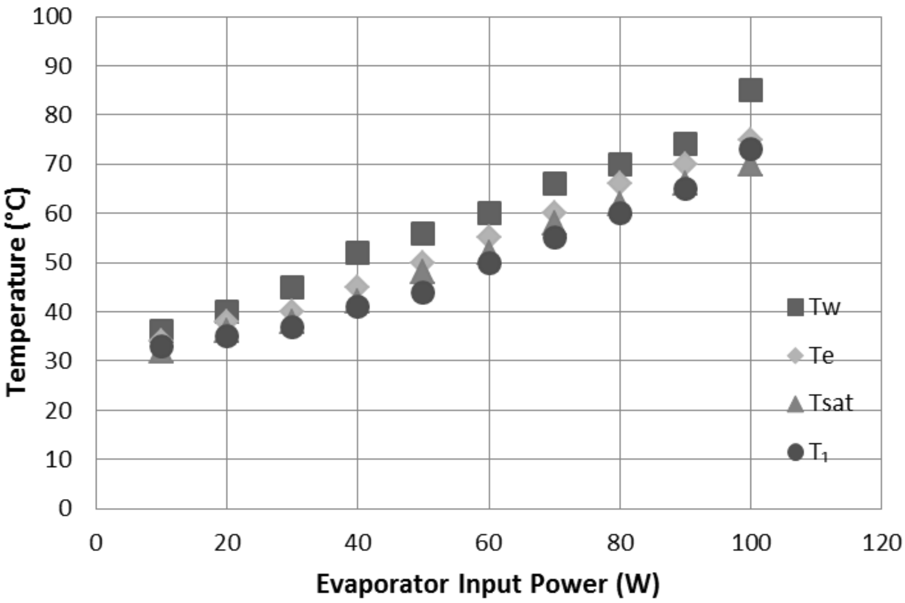



Figure4. Variation of measured average wall temperature in evaporator with Evaporator input power for four fill ratios.




Figuer5. Variation of measured wall,(inlet/out) evaporator and saturation temperature with Evaporator input power at a fill ratio of 50%.

Fig. 6 shows experimental variation of measured saturation pressure with evaporator input power for four fill ratios. It can be seen from the figure that the saturation pressure increases continuously with evaporator input power for all fill ratio. The saturation pressure is inversely proportional to fill ratio. This can be attributed to smaller space that exist when fill ratio increases. This would limit further evaporation which in turn lowers the saturation pressure.

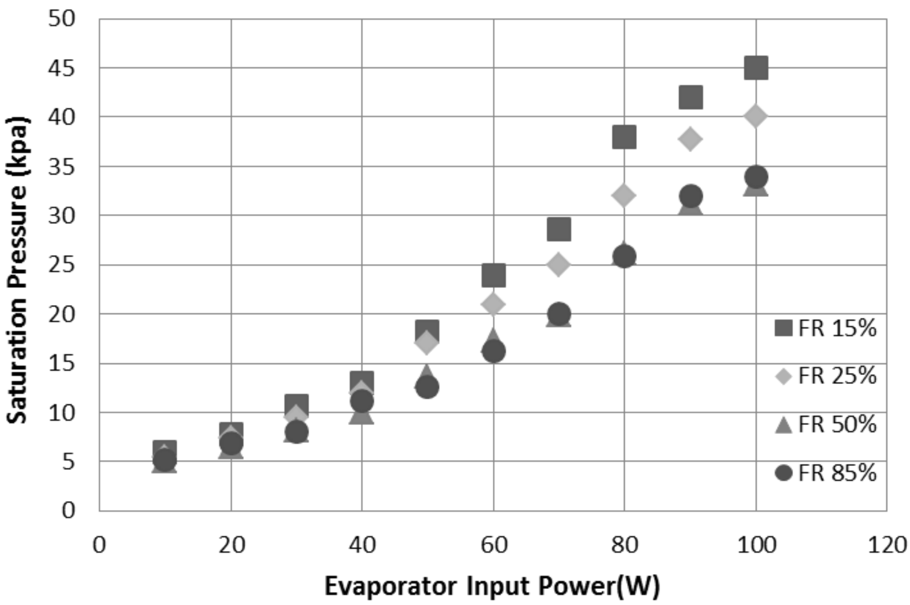



Figure6. Experimental variation of measured saturation pressure with Evaporator input power for four a fill ratios.

Fig. 7 and 8 show experimental variation of measured evaporator and condenser resistances of loop thermosyphon. It can be seen from the figures that the evaporator and condenser resistances decrease with increasing input power. This trend means that the value of the resistance depends on the value of the temperature difference of loop thermosyphon. The figures show that the minimum value of evaporator resistance reached is 0.03 °C/W at the input power 100 W at a fill ratio of 50%. The total resistance is the sum of evaporator and condenser resistance.

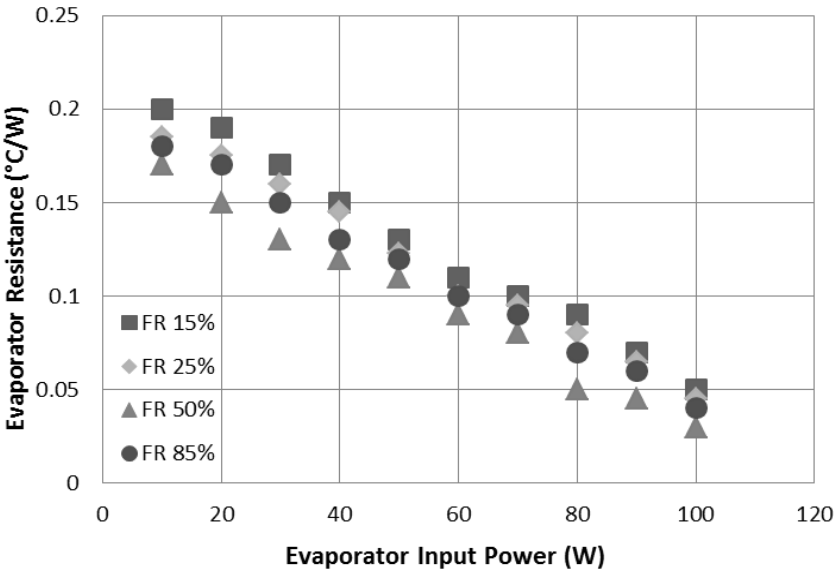



Figure7. Experimental variation of measured evaporator resistance with evaporator inlet power for four fill ratios.

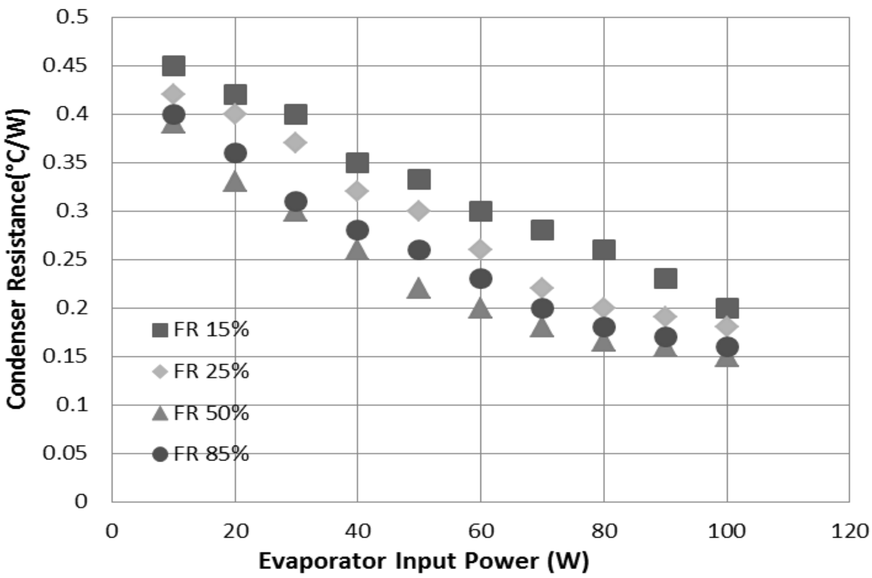



Figure 8. Experimental variation of measured condenser resistance with Evaporator inlet power for four fill ratios.

Fig. 9 shows the variation of total resistance of loop thermosyphon with evaporator input power for the four fill ratios. Results show that the minimum value of the total resistance is 0.2 °C/W at an input power of 100 W and fill ratio of 50%. This is attributed to more uniform flow and heat removal rate.

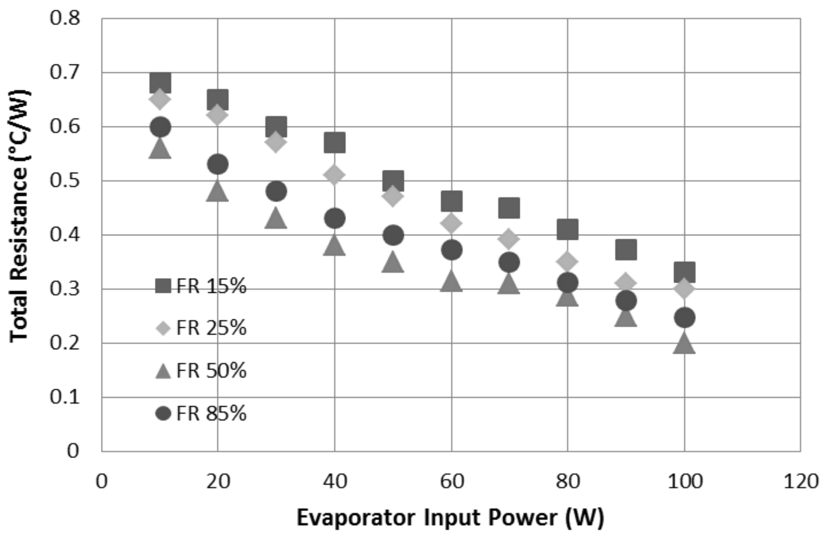



Figure9. Experimental variation of measured Total resistance with Evaporator inlet power for four fill ratios.

Fig. 10 shows experimental variation of measured total resistance with fill ratio at evaporator input powers of 20 W, 50 W and 80 W. The results show that the minimum value of the total resistance was 0.287 (°C/W) at input power of 80 W at a fill ratio 50%. Fig. 11 shows variation of measured evaporation heat transfer coefficient with evaporator input power for four fill ratios. It can be seen from the figure that the evaporation heat transfer coefficient increases with input power for all fill ratios. This trend is physically correct because when the supplied power is increased, the heat transfer to the evaporator increases.

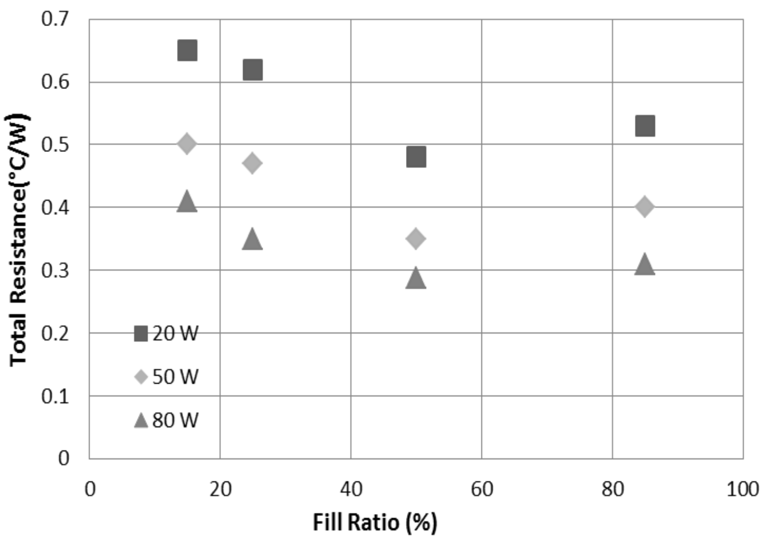



Figure10. Experimental variation of measured total resistance of LHP with filling ratios for three Input power.

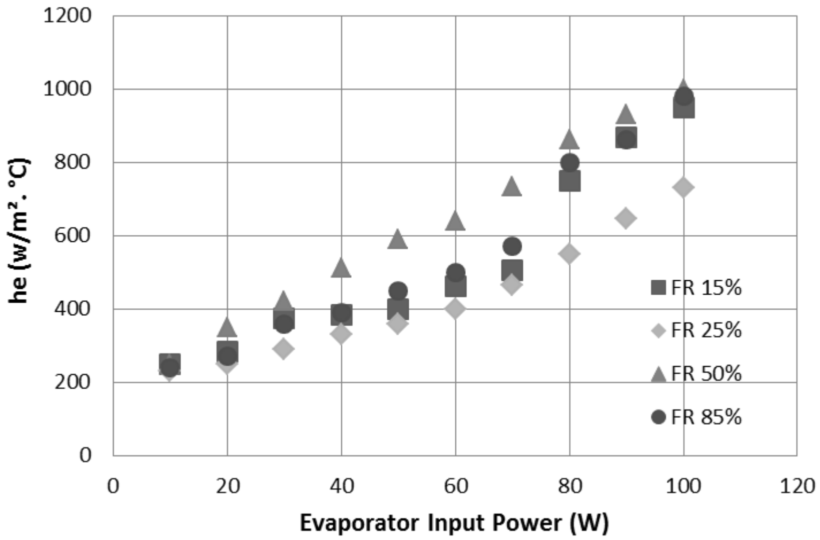



Figure11 . Variation of measured evaporation heat transfer coefficient with Evaporator input power for four fill ratios.

## 6. Conclusions

The present study experimentally investigated the thermal performance of a loop thermosyphon. The focus was on the effect of fill ratio on the evaporator wall temperature and thermal resistances around the loop. It is found that the average wall temperature in the evaporator always increases with power. The minimum value of wall temperature was 80°C at an input power of 100 W and a fill ratio of 50%. Both evaporator and condenser resistances decrease with increasing input power. The minimum value of evaporator resistance was 0.03 °C/W at an input power of 100 W and a fill ratio of 50%**.** The results have been shown that the best value of fill ratio was 50%.

**Symbol List:**

| symbol | The meaning of the symbol | Measuring unit |
|---|---|---|
| A | Area | (m²) |
| Cp | Specific Heat | (Kj/kg.°C) |
| h | Heat transfer coefficient | (W/m².°C) |
| h | Latent heat of evaporation | (j/kg) |
| I | Current | (A) |
| R | Thermal resistance | (°C/W) |
| Q | Heat input | (Watt) |
| T | Temperature | (°C) |
| $\dot{m}$ | Mass flow rate | (Kg/sec) |
| V | Voltage | (Volt) |

**List of Subscripts**

| Symbol | Definition |
|---|---|
| 1 | Inlet |
| Cond | Condenser |
| e | Evaporation |
| Evap | Evaporator |
| in | Input |
| sat | Saturation |
| v | Vapor |
| W | Wall |
| $w_1$ | Water |

## 7. Reference


1. Calvin C. Silverstein (1992), "*Design and Technology of Heat Pipes for Cooling and Heat Exchange*", Hemisphere Publishing Corporation, Washington (USA).
2. Chen K.S., Tsai S.T., Yang Y.W.(1994), "*Heat transfer performance of a double-loop separate-type heat pipe: measurement results*", Energy Conversion and Management, Vol. 35, pp. 1131-1141.
3. Lanchao Lin and Amir Faghri (1998), "*An analysis of two-phase flow stability in a thermosyphon with tube separator*", Applied Thermal Engineering, Vol. 18, No. 6, pp. 441-455.
4. Chehade A. A., Louahlia H., Le S. and Masson (2014)," *Experimental investigation of thermosyphon Loop Thermal Performance*", Energy conversion and Mangemeat, Vol. 84, PP. 641-680.
5. S. I. Haider , Yogendra k. Joshi (2002)," *A Natural Circulation model of the closed loop, Two-Phase Thermosyphon for Electronic Cooling,*" Journal of Heat Transfer, Vol. 124, PP. 881.
6. Yong. J. Park, H. K. Kang, and C. J. Kim (2002), "*Heat transfer characteristics of a two-phase closed thermosyphon to the fill charge ratio*," *Internal Journal of Heat Mass Transfer.*, Vol. 45, pp.4655–4661.
7. Shung- Wen Kang, Meng-chang Tsai, Chih-sheng Hsieh and Jian-You Chen (2010)," Thermal Performance of Loop Thermosyphon," Tamkang Journal of Science and Engineering, Vol.13, No.3,pp.281-288.
8. M. Smitka, M. Malcho, P. Nemec and Z. Kolkova (2013)," *Use of LHP for cooling power electronic components,*" EPJ web of conferences, Vol.45, PP.01046-4.
9. Martin. Z.M. Malcho(2014)," *Impact of the amount of working fluid in loop heat pipe to remove waste heat from electronic component* ," EPJ web of Conferences, Vol.67,PP. 02019.
10. Kai .Z. X. Hailong (2017)," *Dynamic Performance of loop heat pipe for cooling of electronics* ", Journal of Energy procedia, Vol. 142, PP.4163-4168.
11. Y.J. Chen, P.Y. Wang, Z.-H. Liu, and Y.-Y. Li (2013), *"Heat transfer characteristics of a new type of copper wire-bonded flat heat pipe using nano fluids, "Heat Mass Transf.*, vol. 67, pp. 548–559.

12. A. B. Solomon, R. Roshan, W. Vincent, V. K. Karthikeyan, and L. G. Asirvatham (2015),"*Heat transfer performance of an anodized two-phase closed thermosyphon with refrigerant as working fluid*, "*Heat Mass Transf.*, vol. 82, pp. 521–529.