HOW FAR CAN THE WORKING FLUID FILLING RATIO AND TYPE INFLUENCE THE THERMAL BEHAVIOR PERFORMANCE OF THE THERMOSYPHON?

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Abstract— **This work intended to assessment the thermal behaviour of a thermosyphon harnessing the fluids those commonly used namely such as water, acetone and freon134a as a working fluid, with filling ratio (50%, 60%, and 70 %) , Corresponding to approximately half filled and overfilled evaporator section in order to ensure enough area for evaporation and condensation process, respectively. The adopted commercial thermosyphon was made of a copper tube material with inner diameter of 26mm and outer diameter of 24 mm. Experimentally, tests were conducted at a below 85°C. The thermal performance of the thermosyphon charged Freon 134a, outperformed the other two working fluids in the effective thermal resistance, maximum heat dissipations and maximum heat transport capabilities. Distilling water which is the lowest saturation temperature fluid tested, shows low thermal performance in the heat transfer comparing with freon134a and acetone. At the higher operating temperature, result indicated that the fill ratios greater than 60 percent, the thermosyphon show better results in terms of improved overall heat transfer coefficient, reduced thermal resistance, increased maximum heating time, increased heat dissipation input power of (100, 200 and 300) Watt. While the operating oil temperature was maintained. While at lower operating temperature, the fill ratios 50 percent gave better result in terms mention above.**

Keywords— Thermosyphon, Thermal Resistance, Thermal Performance, Filling Ratio, Heat Dissipation.

I. INTRODUCTION

Due to its efficacious characteristics of low thermal resistance, a thermosyphon is reckoned as a functional heat dissipation device in engineering multi-disciplines [1, 2]. A surge interest has been witnessed in recent years to the thermosyphon in a wide spectrum of applications, especially, power savings and environmental issues. Their application had become a hot research platform in renewable energy sources, heat recuperation of small-grade heat energy and refrigeration equipment, e.g., solar heating of building [3], extraction of geothermal energy for power generation [4, 5], solar thermal appliances [6], cooling of the turbine blade and transformer [7, 8] and so on.

All thermosyphon are composed of two parts: a condenser section and evaporator section at a time with an adiabatic section between these sections. The heat received from the heat sink by the thermosyphon evaporator section is transferred into a working fluid to evaporate at very low pressure. This vapor moves upward due to the pressure difference amongst the two sections, along with the aid of buoyancy force towards the condenser section. Ultimately, the vapor rejects the latent heat to the surrounding through the condenser section, condenses to liquid and returns to the evaporator section by gravity for another cycle. Abdullahi et al. [9]. A variety of numerical analysis and experimental work were done on the thermosyphon by study its characteristic and the influence of different parameters on their performance. Maa et al. [10] investigated the thermal performance of thermosyphon using different working fluids such as (R134a, R601, R245fa, R600a, R1234ze, R152a, R245fa/R152a and R601/R245fa). The thermosyphon was made from a copper pipe with 40 mm diameter and 3 m long. The obtained results where show that working fluid R245fa / R152a give the best heat dissipation than the other working fluids. Andrzejczyk, R. [11] studied the influences of different parameters on performance of a wickless heat pipe, using different input powers range from 300W to 50W. The investigations were carried out by a cooling water to cooling the condenser section at constant inlet temperature and constant mass flow rate with different working fluids (water, ethanol, and SES36 (1, 1, 1, 3, 3-Pentafluorobutane)) and different filling ratios (0.32, 0.51, 1.0). The obtained results shown that the thermosyphon thermal resistance decreased with increasing in the input power and increased with increasing in the filling ratio. Mozumder. A. K, et al. [12] investigated the thermal performance of thermosyphon using different working fluids such as water, methanol and acetone and different filling ratios (0.35, 0.55, 0.85, and 1.0). The obtained results where show

that working fluid acetone with 100 %filling ratio will gave best performance in terms of heat transfer coefficient and reduced thermal resistance.

Herein, in the present work, an effort has been made to shed the light on the thermal performance of the thermosyphon. More precisely, to probe the heat dissipation rates from an electric transformer's oil aiming to enhance the cooling rate of that oil. Besides, to scrutinize the thermal performance of thermosyphon in terms thermal resistance, overall heat transfer coefficient and through utilizing thermosyphon with different filling ratios, different working fluids and at different input powers.

II. EXPERIMENTAL WORK

A. Test Rig Setup

As depicted in Figure 1, the test rig comprises three major parts; the thermosyphon reservoir (oil tank), electrical heater and the measuring devices. The thermosyphon tube was fabricated from copper material, with a 24 and 26 mm as inner and outer diameters, respectively. The length of thermosyphon condenser and evaporator parts was 250 mm without the adiabatic part. The evaporator section was immersed in the hot oil, while the condenser section of the thermosyphon was subjected to air. This would facilitate the heat loose to the atmosphere by natural free convection.

The oil reservoir (tank) was manufactured from a galvanized metal sheet of 2 mm thickness and having a dimension of (400, 300 and 200) mm. The top surface of the oil reservoir has three ports. The first one was used to fix the electrical heater at the center of the top surface, while the other two ports, at the sides of the top surface, were used to fix the thermosyphon. The oil reservoir was filled with 24 liters of electrical transformer oil.

An electrical heater was utilized for heating the oil. This heater has 270mm length and 1000-Watt power capacity. A dimmer switch, with reading accuracy of ($\pm 1\%$) and Watt meter with a reading accuracy of ($\pm 0.5\%$), was harnessed to endow various input powers (100, 200 and 300) Watt.

Seven thermocouples (type k) (chromel-alumel), having a measurement error of $\pm 0.5°C$, were employed to measure the temperature at different positions. Three of these thermocouples were installed at different positions on the top of the oil surface (near the heater (T1), mid of the distance between the heater and the thermosyphon (T2) and on the surface of thermosyphon evaporator (T3). Also, another three thermocouples were placed at different positions on the surface of the thermosyphon condenser (bottom (T4), middle (T5) and top (T6)). The seventh thermocouple was employed to measure the ambient temperature (T7), as shown in Figure 2.

The setting procedure begins firstly with cleaning the thermosyphon from inside several times using acetone. This was followed by the evacuating process to -760 mmHg (gauge pressure) via a vacuum pump. Following this step, filling the thermosyphon with the working fluid at the required value of the filling ratio. where the fill ratio here is the percentage of the volume of the evaporator portion that is filled by the working fluids, the filling ratios used in this experiment were 50 %, 60 %, and 70 % of the evaporator volume for the three separate working fluids. Finally, choosing the input power (100, 200 and 300) Watt for heating the oil. All the measured temperature, at the seven points on the test rig, were taken for all three working fluids for all the fill ratios after reaching steady state condition by thermocouples were recorder by 12 channels data logger (BTM-4208SD data logger temperature recorder), It is arranged in Excel Sheet**.**

All the experimental tests were carried from the ambient temperature to operating temperature below 85°C.
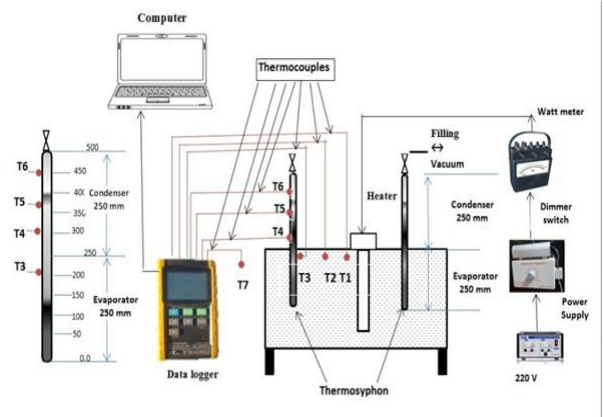

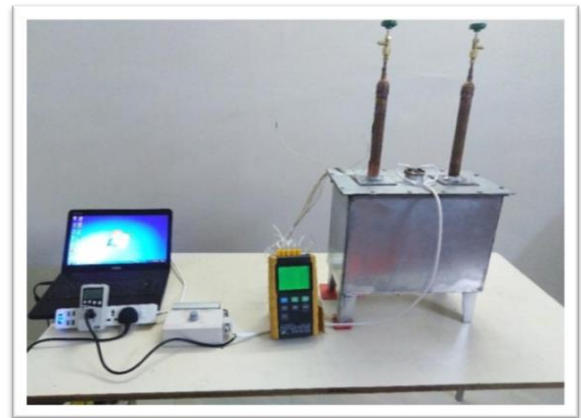Fig 1: Thermosyphon test rig

Fig 2: Sketch of thermocouples location on thermosyphon test rig

B. Calculation procedures

To appraise the thermal performance of the thermosyphon heat pipes, it is indispensable to probe the heat dissipation from oil by the thermosyphon. This could be calculated as given in the equations below [13];

Qoil = m×Cp×ΔT   (1)

Also, the specific heat of the oil can be calculated by the following equation [14]:

Cp =807.163+3.58× Toil   (2)

Qoil dissipation = Qoil(without thermosyphon) – Qoil(with thermosyphon) (W)   (3)

Where the thermal resistance of thermosyphon R can be calculated as [15]:

$$R = \frac{Te - Tc}{Q\,in} \quad \left(\frac{°C}{W}\right) \qquad (4)$$

And the overall heat transfer co-efficient is given by[12]:

$$h = \frac{Q}{A\,(T_e - T_c)} \quad \left(\frac{W}{m^2 . °c}\right) \qquad (5)$$

where   Q : Heat Input (W).
   m : mass of the oil (kg).
   Cp: specific heat of the oil (W/kg.k).
   ΔT: oil temperature difference (°C).
   R : Thermal Resistance (°C/W).
   h : Overall heat transfer Coefficient (W/m2 -°C).
   A : heat transfer surface area at the evaporator (m^2).
   Tc : Average Condenser part Temperature (°C).
   Te : Average Evaporator part Temperature (°C).

C.   *Uncertainty analysis*

The uncertainty of the thermosyphon thermal resistance can be calculated from readings of the temperature along the thermosyphon and the input power.

$$\frac{u_R}{R} = \sqrt{\left(\frac{u_{\Delta Te-c}}{\Delta Te-c}\right)^2 + \left(\frac{u_{qin}}{Qin}\right)^2} \; [16] \qquad (6)$$

Where: $u_{\Delta Te-c} = \sqrt{\left(u_{\Delta Te-av}\right)^2 + \left(u_{Tc-av}\right)^2}$ The value of uncertainty associated with $\Delta Te - c$: u_{Qin} The value of uncertainty associated with the reading of the power Qin

Also, the: $\Delta T_{e-c} = T_{e-av} - T_{c-av}$

Where:

 Te-av = T3 average temperatures in the evaporator section.

Tc-av = $\frac{(T4+T5+T6)}{3}$ average temperatures in the condenser section.

By measuring $\frac{u_R}{R}$ for the entire experimental range, the overall uncertainty associated with the resulting R values was found to be about 2.7%, an reasonable value for engineering applications.

III.   RESULT AND DISCUSSION

The thermosyphon was experimentally tested to cognition of thermal performance, under the influence of different filling ratios and different working fluids with a variety of input power. The specification below was considered:
 Input power: 100 W, 200 W, 300 W
Filling ratio: 50%, 60%, 70%
Working fluid: Water, Acetone, Freon134a
Tube material of thermosyphon: Copper
Total length of thermosyphon: 500 mm
Length of Condenser part: 250 mm
Length of Evaporator part: 250 mm
In this work, the symbols T1 and T2 represent the values of average oil temperature and the symbols T3, T4,T5, T6 the values of thermosyphon wall , respectively. Also the symbol T7 represented the value of ambient temperature. as demonstrated in Fig. 2.

A: The effect of working fluids on the temperatures distribution on thermosyphon wall
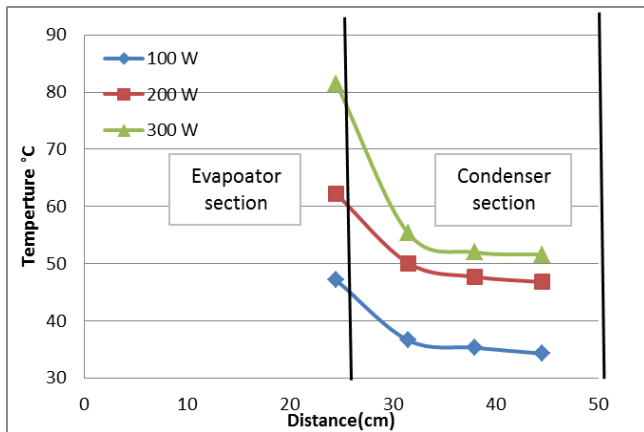
The temperature distribution along the wall of the thermosyphon at a filling ratio of 60% and a various input power is exhibit in Fig. 3 (a, b, c) for Water, Acetone and Freon134a, respectively. It demonstrates that the slope of the axial temperature distribution tends to increase with the heating rate and exhibit high temperature differences throughout the condenser and evaporator section for all working fluids. In case of acetone and Freon 134a the slopes of axial temperature distributions are more stability at condenser section. While the slopes of axial temperature distributions for the water shows less stability than acetone and Freon 134a. It is worth mentioning that the stability in slopes of axial temperature distributions occurs when the rate of vapor condensation process in condenser part equal to the evaporation process in evaporator part.
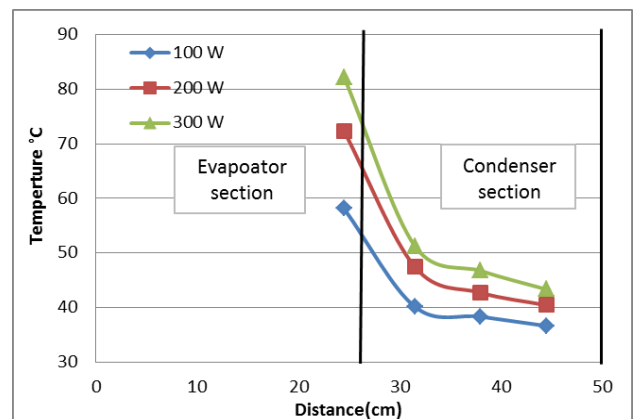
(a)
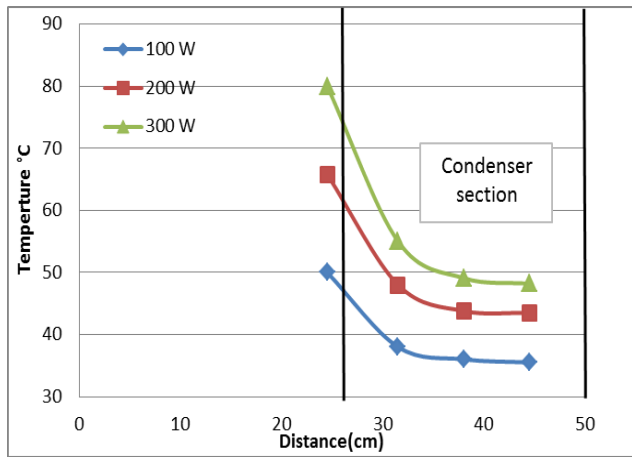
(b)

(c)

Fig 3 (a, b,c): Temperature distribution along the wall of the thermosyphon at a filling ratio of 60% for working fluid (a)Water, (b)Acetone and (c)Freon134a.
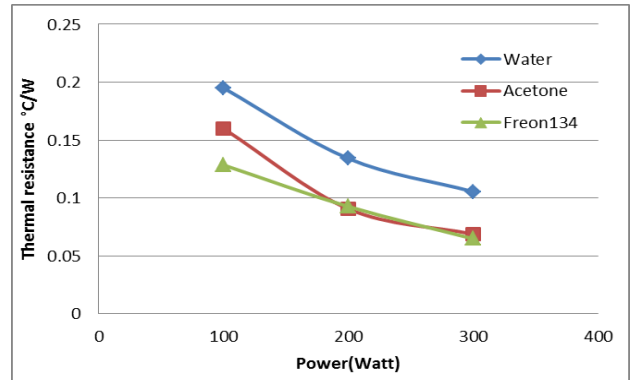
B. *Effect filling ratio on thermal resistance (R)*

The variations of thermal resistances with different heat inputs for water, acetone and freon134a for filling ratios (50%, 60% and 70%), respectively. It shown in Figure 4 (a,b,c). This demonstrates differences and contrasts of thermal resistances that occur at various filling ratios for the three different working fluids at various input powers. In general the figure elucidated that the thermal resistance of thermosyphon was decreased with increasing the input power and reached the lowest value at an input power of 300.

In case of water The Figure 4 (a,b,c) depicted the best thermal performance of thermosyphon at a filling ratio of 0.5 and an input power of 100 Watt. While Figure 4(b) manifested the greater thermal performance of the thermosyphon at 0.6 filling ratio for the input powers of 200 and 300 Watt.

In case of freon134a and acetone. There is a convergence in the thermal resistance value at the 200Watt and 300 watt input power and the effect of the filling ratio is ineffective, while the freon134a is preferred at a 50% and 70%filling ratios with power input 100 watt.
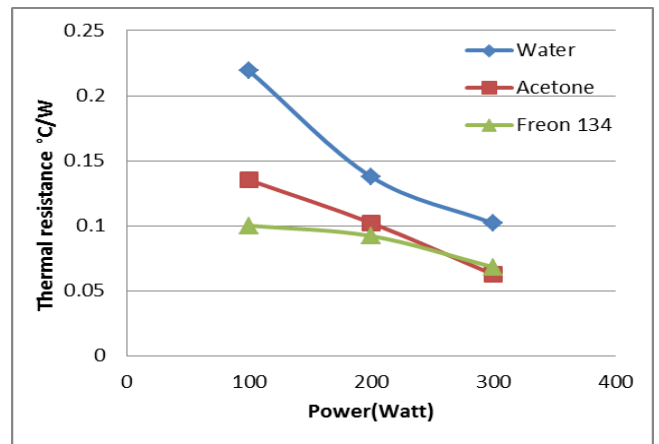
Obtained results recommended using a water and Freon134a with 0.5 filling ratio in the case of low input power, while in the case of a higher input power value of 0.6 filling ratio for all working fluid would be used.
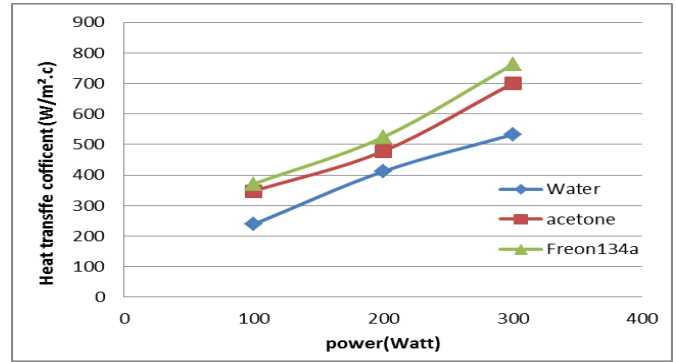

(a)
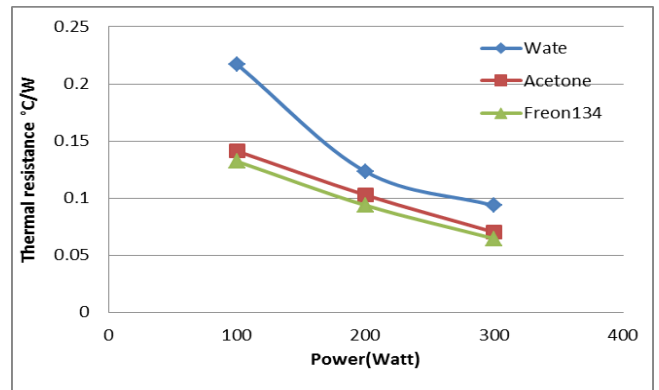
(b)

(c)

Figure 4(a,b,c): variation of thermal resistance for working fluid with Heat Input for filling ratio (a) 50%,(b)60% and (c)70%.

C: Variation of Overall Heat Transfer Co-efficient (h) with Heat Input:
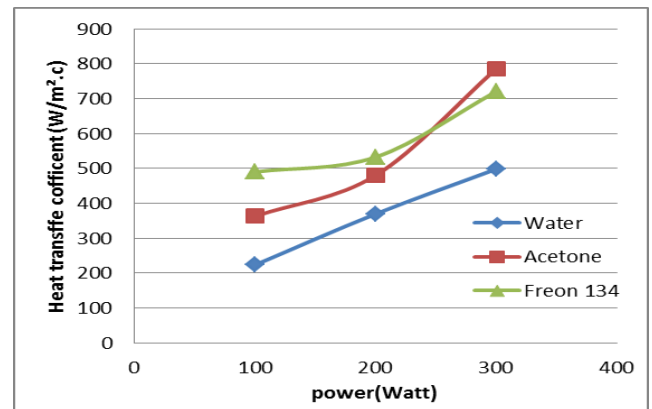
Variation the overall heat transfer coefficient for the water, acetone and Freon 134a at different heat input power, has been elucidated in Figure 5A-5C, respectively. These readings are taken for the three filling ratio (50%, 60% and 70%), adopted in this work. When the thermosyphon charged with working fluids, the heat transfer coefficient increases remarkably due to the increased rate of heat transfer resulting from the evaporation processes in the evaporator part and the condensation process in the condenser part.

The figures disclosed that the water has smallest Overall Heat Transfer Co-efficient for all input power and all filling ratios. While the Freon 134a has biggest Overall Heat Transfer Co-efficient for all input power and all filling ratio, except at 300 W and filling ratio 70%, acetone show high performance as Heat Transfer Co-efficient.

Trends in the curves of the overall heat transfer co-efficient in the current work of all working fluids, an increase appears at the overall heat transfer co-efficient with an increase in the heat input, and this leads to the possibility of obtaining an increase in the operating range, due to in this case the rate of condensate vapor return was been higher than the rate of evaporation liquid.
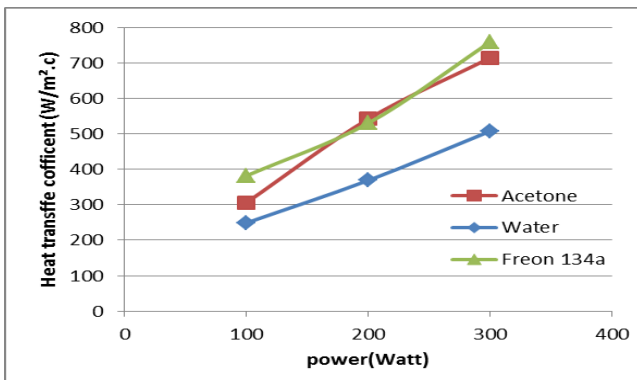

(a)

(b)

(c)

Figure 5(a,b,c): variation of heat transfer coefficient (h) with Heat Input for filling ratio (a) 50%,(b)60% and (c)70%.

d. Maximum heating time

The maximum heating time required to reach the same level of the average oil temperature, at different filling ratios and different working fluids, is given in Figures (6 to 8). These values of maximum time are taken for three input power (100, 200 and 300) Watt, respectively, with and without using thermosyphon. The heat dissipation rate was found to be directly proportional to the heating time. The highest heat
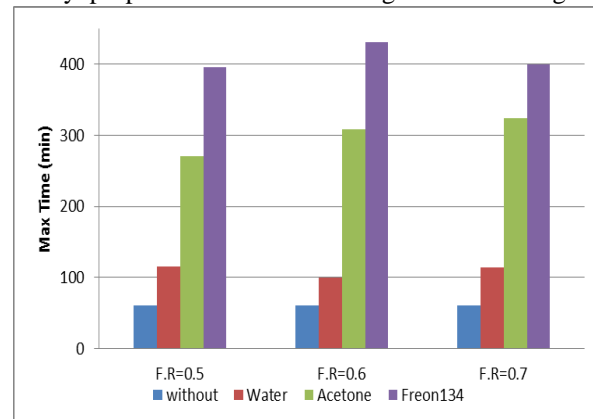
dissipation rate by the thermosyphon is leading to the highest heating time that gives the best thermal performance of the thermosyphon indeed. Figures (6 to 8) depicted the best thermal performance of thermosyphon for Freon 134a at all input power and at a filling ratio 0.6. also the filling ratio 0.7 gives best thermal performance for acetone. Obtained results recommended using a freon134a with 0.6 filling for all level input power, while 0.7 fill ratio for the acetone and water.

Figure 6:relationship between maximam heating time for the working fluids and filling ratios for power supply 100
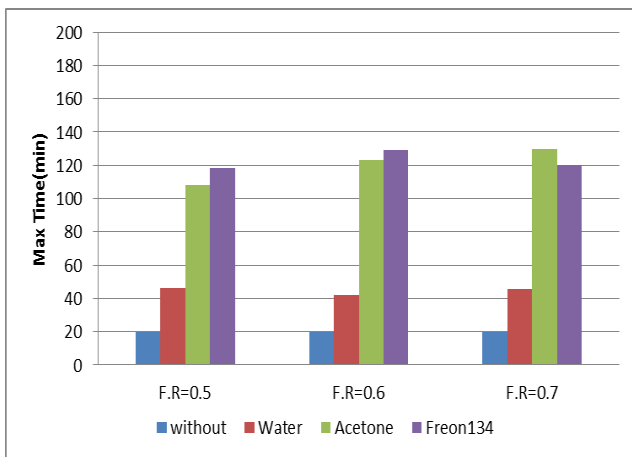

Figure 7:relationship between maximam heating time for the working fluids and filling ratios for power supply 200 W
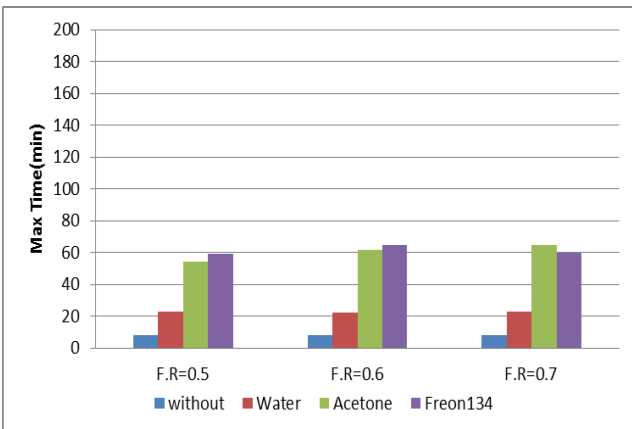

Figure 8:relationship between maximam heating time for the working fluids and filling ratios for power supply300 W.

E. heat dissipation

In this contest, the Figure (9) heat dissipation from the oil at adopted working fluids and input powers are illustrated in Figure (9) below. The findings indicated that the amount of

heat dissipation rises with increasing the input power magnitude. In the meantime at all input power 100,200 and 300 Watt, it was demonstrated that acetone and Freon 134a can endow a higher dissipation rate among with advantage for acetone at 300 watt. However, this was not the scenario for the water where the amount of heat dissipation was less.
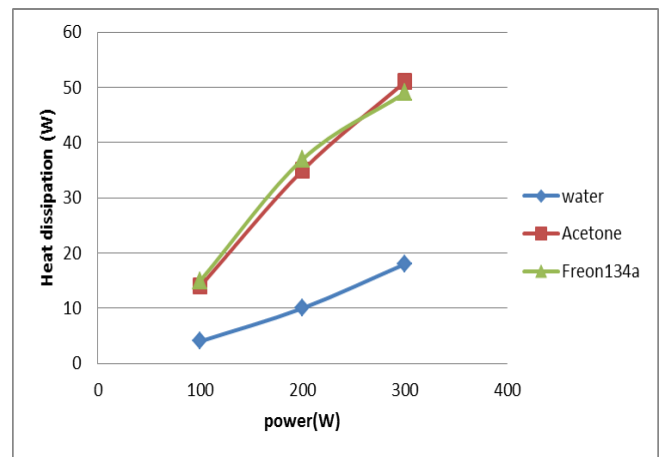

Figure 9: the heat dissipation with respect input power at the different working fluid

IV.   CONCLUSION

Based on the work conducted herein, several conclusions could be drawn, as follows:

1. When the input power increased the steady state of temperature distribution increases. The slope axial temperature distribution on the thermosyphon wall shows stability temperature with heat input increased.

2. The values of the thermal resistance of the thermosyphon have decreased with increasing the input powers for all values off filling ratios. At the filling ratio of 0.5for the water, the percentage decrease in the thermosyphon thermal resistance was 11.6 %, compared with the filling ratio of 0.7 at an input power of 100W. While the effect of filling ratio is shown minimum effect on the performance of thermosyphon at input power 200 W and 300W for all working fluid.

3. In the set of inputs calculated for working fluids (freon134a, acetone and water), the average heat transfer coefficient of the thermosyphon rises with an increase in heat power supply, whereas the water gives less performance in terms heat transfer co-efficient comparing with other fluid. Additionally

the acetone gives high performance at filling ratio 0.7 and power input 300 Watt.

4. The rate of heat dissipation increases proportionally with increasing the input power. Also, the Freon 134a at filling ratio 0.6 can bestow higher performance from other filling ratios, at low input power. While in the case of higher input power, the effect of filling ratio was minimum for all working fluids.

5. The rate of heat dissipations from the oil increasing proportionally with increasing input power, whereas the freon134a and acetone gives high performance in terms heat dissipations.

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