Factors Affecting Thermosyphon Performance -A Review of Studies

Rajeanderan Revichandran, A.K.M. Mohiuddin, Mohammad Faisal Uddin

Abstract: ***The utilization of the two-phase thermosyphons (TPTs) is expanding for some warmth exchange applications. This paper reviews the performance of thermosyphon TPT systems. The impact of the influencing parameters on the execution of TPTs for example geometry, filling ratio ,working liquid and the inclination angle by different researchers are discussed. The various working limits happening in a thermosyphon that includes dry out, and flooding affects likewise examined. Based on many factors reviewed it shows that the filling ratio exerts small influence in heat transfer and influence is more noticeable for inclination angles. Circulation of working fluid that aided by effects of gravity disable thermosyphon to perform in horizontal position .In addition, it is expected dry out effect could easily occur in the case of high power input, low fill ratio and high inclination angle. This paper could utilize as the beginning point for the researches keen on the TPTs and their renewable energy applications.***

Keywords: ***Heat Transfer Coefficient; Thermal Resistance; Inclination Angle; Two Phase Thermosyphon; Dry-out limitation; Filling Ratio***

I. INTRODUCTION

A two-phase thermosyphon is highly effective passive heat transfer system. Generally, it consists of an evacuated tube that filled with working fluid at a rated filled ratio to transport heat throughout the system. A thermosyphon is divided into three parts; an evaporator section, adiabatic section (transport) and condenser section. It may have multiple heat sources or sinks with or without adiabatic sections depending on specific application and design. It works by absorbing latent heat of vaporization from a heat source. It is a fact that thermosyphons are very effective, low cost and reliable heat transfer device for many thermal and heat recovery applications. The TPT technology has found increase interest of the researches in a wide range of applications from small-scale to large-scale systems. TPTs are use in chemical and petroleum industries, electronic cooling, telecommunication devices, energy storage systems, thermoelectric power generators, seasonal cooling, and load reduction of buildings.

II. WORKING PRINCIPLE

Fig. 4 shows a basic working principle of a thermosyphon. It is a highly efficient heat transfer device where it utilizes the principle of evaporation and condensation of the working fluid. It works by transferring latent heat of evaporation of the working fluid inside the system, which have been transport continuously by changing its phase from liquid to gas. As the amount of the heat absorbed increases, the vapor produced will be transport through the adiabatic section. Its low density causes it to flow upwards to the condenser end of the thermosyphon, at which it condenses back into liquid state by releasing the absorbed latent heat to a heat sink. As it condenses and the working fluid takes liquid state due to increasing in density, the liquid is drive back to the evaporator end by gravity. This cycle repeats continuously resulting in heat transfer to take place between the evaporator end and the condenser end of the thermosyphon. The basic working principle of a thermosyphon illustrated in Fig. 1 [1].

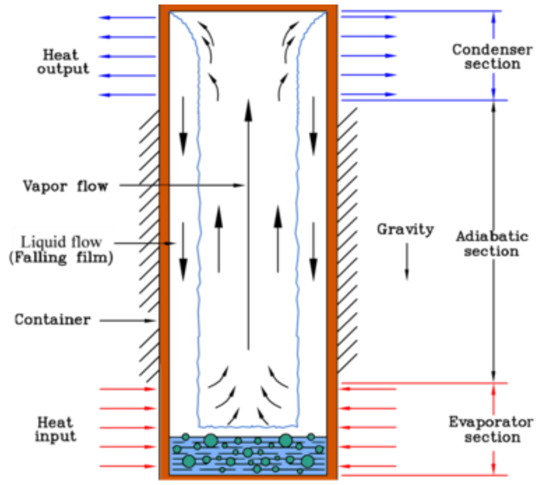

Fig. 1 Basic Working Principle of a Thermosyphon

III. FACTORS AFFECTING THERMAL PERFORMANCE OF THERMOSYPHON

From the literature survey mainly it was observed that the following factors affect the thermal performance of two-phase thermosyphon:

1. Geometry (distance across, shape and length)
2. Working fluid properties
3. Filling ratio
4. Aspect ratio
5. Heat load
6. Inside pressure of thermosyphon
7. Thermosyphon material properties and dimensions Length of various sections (evaporator section, adiabatic section and condenser section).

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IV. IMPORTANT REVIEW WORKS

Many investigations been carried out in order to analyze the thermal performance of a thermosyphon and many have looked into different factors that influence its performance. These are as follows.

Amatachaya et al [2] compared the heat transfer characteristics of a flat two-phase closed thermosyphon (FTPCT) and a conventional two-phase closed thermosyphon (CTPCT). In the investigation thermosyphons with inner diameter of 32 mm and length of 980 mm were compared by varying the heat input, filling ratio and aspect ratio. From the results it was reported that the heat transfer coefficient of the CTPCT and FTPCT increased with decrease in filling ratios. Based on their finding it shows that thermosyphon structure has significant effect on overall heat transfer coefficient.

Kyung Mo et al [3] compared the thermal performance between annular and concentric thermosyphons with individual length of 215 mm and inner and outer diameter of 22 mm and 25.4 mm at different fill ratios. Both the thermosyphons performance were studied based on changes of the entrainment limit at different fill ratio. Based on their findings concentric thermosyphons has enhanced the entrainment limit far better than an annular thermosyphon as the fill ratio increases. This is because reduction of the cross-sectional area for vapor flow results in increase of the shear at the vapor–liquid interface causes such enhancement.

Hasna Louahlia et al [4] studied the evaporation and condensation heat transfer coefficients for looped thermosyphon. The investigation carried out by varying the heat load throughout the experiment. Result shows that condenser and evaporator thermal resistance decreases as heat load increases which are parallel with finding of Kyung Mo and In Cheol [3] who also determined similar result from their investigation. Eventhough Kyung and In Cheol [3] and Hasna et al [4] studies involve different structure type of thermosyphons it could be observed that both their findings are parallel which shows that increase in heat load plays a important role towards thermosyphon performance although different structures used.

Thanaphol et al [5] studied the affects of using a flexible hose in a thermosyphon at the adiabatic section by using R-134a as working fluid. The experiment conducted by varying the flexible hose angle at different heat load. Based on their study it found that bending the pipe had a significant effect on two-phase thermosyphon flow pattern and pressure drop in the pipe. The higher the pressure drop, the higher the evaporation temperature. This proves that even though a small change in structure can varies the thermosyphon performance.

Khalid and Witwit [6] carried out investigation on the performance of conventional two-phase thermosyphon with a modified separator at the adiabatic section. The thermosyphon constructed with closed copper tube with a length of 1000 mm and inner and outer diameters of 26 mm and 32 mm. The adiabatic section length varies at 100 mm, 300 mm and 700 mm. The performance of the altered two-phase thermosyphons was compare with a conventional two phase thermosyphon. Results showed that the usage of the adiabatic separator overall improved the two-phase thermosyphon performance, which tested for all lengths and inclination angles. Both the findings of Thanaphol and Naris [5] and Khalid and Witwit [6] show that altering the adiabatic section has a significant effect on the performance of the thermosyphon. Thus this indicates that structure and geometry of a thermosyphon plays a very important role towards its performance.

Anjankar and Yarasu [7] studied the experimental analysis effects of condenser length on the performance of two-phase vertical closed thermosyphon with different flow rates of 6, 8 and 10 liter per hour to condenser and heat input to evaporator. The result shows that the thermal performance of thermosyphon at heat input 500 W and flow rate 0.0027 kg/s with condenser length of 450 mm is highest. In overall it was conclude that condenser length should be 1.5 times to that of evaporator length to obtain better thermal performance. Fig. 2 shows their findings. Similar to Thanaphol and Naris [5] and Khalid and Witwit [6], Anjankar and Yarasu [7] showed that performance of the thermosyphon are been influenced by varying its dimensions.

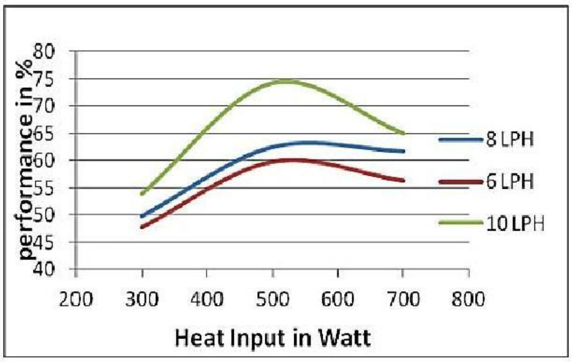

Fig. 2 Performance of Thermosyphon at Various Flow Rates

Brusly Solomon et al [8] have carried out experimental study on thermal performance of anodized two phases closed thermosyphon (TPCT) with length of 350 mm and inner and outer diameter of 14.9 mm and 16.5 mm. The investigation was carried out to study the thermal resistance and thermal stability of the anodized surface prepared on the inner wall of the TPCT. The anodized and non-anodized TPCTs are charged with acetone as working fluid and tested by varying its heat input ranging from 50–250 W. Result shows that heat transfer coefficient of anodized is larger than non-anodized at all heat input values. Moreover, it was also observed that the thermal resistance of the anodized TPCT is smaller than non-anodized TPCT due to the reduction in the thermal resistance of the evaporator. From the thermal stability test it was confirmed the feasibility use of porous coating in the TPCT. Fig. 3 shows their results.

Renjith Singh et al [9] studied the effects of anodization on the heat transfer performance on flat thermosyphon by using acetone as working fluid. The anodization performed by applying porous coating and a gap of 3 mm was maintained between the anode and cathode to ensure uniform

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coating. The obtained results later were compared with a cylindrical thermosyphon to see their differences. Overall result shows that fill ratio and inclination angle has a significant effect on thermosyphon performance and the thermal resistance of anodized thermosyphon is reduced by 20% compared with non-anodized thermosyphon. This finding is parallel with Brusly Solomon et al [8] which determined that thermal resistance of the anodized TPCT is smaller than non-anodized TPCT. The maximum enhancement in heat transfer obtain from anodized compare to non-anodized thermosyphon is 27%. In overall the flat thermosyphon was found to be better performing compared to cylindrical thermosphon and heat transfer coefficient of flat thermosyphon at evaporator and condenser higher by 69% and 56% respectively compare to cylindrical thermosyphon at heat flux of 50 kW/m^2.

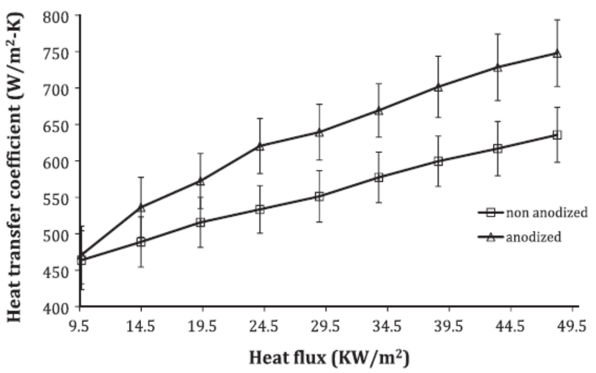

Fig. 3 Heat transfer Coefficient at Varies Heat Flux for Anodized and Non-anodized

Ong et al [10] investigated the thermal resistance of a thermosyphon at different fill ratios and inclination angles (30°, 60° and 90°) by using R410A refrigerant as working fluid. The thermosyphon is made of copper tube length of 930 mm and inner and outer diameter of 9.5 mm and 12.7 mm. From their study it was reported that thermal resistance of thermosyphon shows that fill ratio and inclination angle did not have significant effect on the thermal performance. However it was observed that inclination angle of 60° performed better compared to other inclination angles of 30° and 90°. Moreover it was observed the thermosyphon wall temperature increases along with input power and it was expected that dry out effect could have easily occurred in the case of high power inputs, low fill ratios and high inclinations. It was concluded that R410A filled thermosyphon performed better in the vertical position at all fill ratios whereas water filled thermosyphon performed better at lower fill ratios.

Yong et al [11] studied the heat transfer performance of a two-phase closed thermosyphon with outer diameter of 22.2 mm at various filling ratios by using FC-72 (C_6F_{14}) as working fluid. The experiment was conducted within heat input range of 50–600 W and fill ratio of 10% –70%. It was reported the effects of filling ratio on heat transfer coefficient of the evaporator was nearly negligible. Nevertheless, at the condenser section the heat transfer coefficients showed some improvement with the increase of filling ratio as the pool of working fluid continues expanding and the heat transfer coefficient appeared in different ways to the fill ratio. For relatively small fill ratio (< 20%) dry-out phenomena occurs and limits the performance at maximum heat flow rate of 100 W. This finding is similar with Ong et al [10] that observed dry out effect could easily occurred in the case of high power inputs, low fill ratios and high inclinations. Whereas, for a large fill ratio flooding limitation occurs and the maximum heat flow rate limited about 500 –550 W. Thus indicates that there is limit for each system performance.

Payakaruk et al [12] carried out experiments to predict heat transfer characteristics of an inclined closed two-phase thermosyphon and their effects on the heat transfer rate by using R22, R123 and R134a as working fluid. The experiment carried out by using copper tube with outer diameter of 7.5, 11.1 and 25.4 mm at different filling ratios, aspect ratios and inclination angles. Based on the result it was determined that filling ratio has no considerable effect on heat transfer characteristics at any angle. Their findings are correlated with Ong et al [10] team who also observed that fill ratio and inclination angle did not have significant effect on the thermal performance. However, the working fluid properties are been affected by the heat transfer characteristic. In addition, lower the latent heat of vaporization, higher the Q/Q_{90}. From the further study, a correlation established between Q/Q_{90} and the modified Ku. The correlation is as follow:

$$\frac{Q}{Q_{90}} = 1.678 Ku^{0.0196} \quad (1)$$

Ong et al [13] investigated effects of thermosyphon filled with R410A refrigerant and water at different fill ratios and inclination angles. The thermosyphon made of copper tube with length of 760 mm and inner and outer diameter of 32 mm and 38 mm. Fig. 4 shows the schematic of the experiment. The result shows that the thermosyphon wall temperature increased with increasing input power. Moreover it was observed fill ratio and inclination angle did not have significant effect on the thermal performance. It was concluded that R410A filled thermosyphon performed better in the vertical position at all fill ratios. Their results were in contrast with which findings of Payakaruk [12] who observed that fill ratio has no visible effect on thermosyphon performance. Thus this shows that different working fluid could affect the performance of the thermosyphon.

Manimaran et al [14] studied the effects of filled ratio on thermal characteristics of wire -mesh pipe using copper oxide nanofluid and distilled water. The experiment was carried out with CUO and Water as working fluid at concentration of 1.0 %wt with thermosyphon length of 600 mm with inner and outer diameter of 20.8 mm and 22 mm. In this study, the thermal characteristic of nanofluid and deionized water (DI) compared based on effects of heat input, fill ratio and angle

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of inclination. The result shows that thermal efficiency for DI water and nanofluid increases with fill ratio increases and the maximum efficiency are obtain for 75% fill ratio and for an angle of 30°. From their study, it reported that the heat pipe that uses nanofluid as the working fluid shows higher thermal efficiency than the heat pipe using DI water. Based on the study it was conclude that nanofluids have higher potential for heat transfer enhancement compare to DI water.

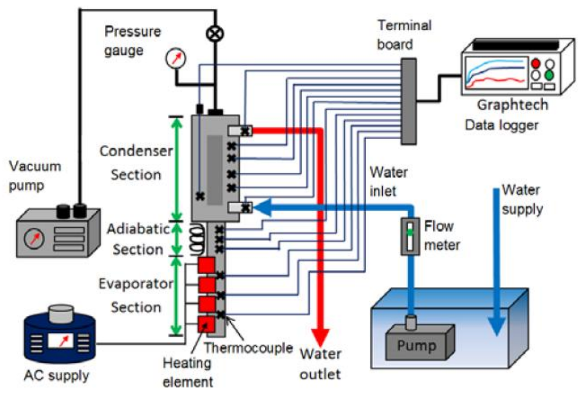

Fig.4 Schematic of Experiment Set Up

Shanthi and Velraj [15] performed an investigation on heat input at different fill ratio by using nanofluids and pure water as working fluid with thermosyphon length of 300mm and outer diameter of 12.5 mm. Result shows that the temperature distribution along the thermosyphon was of lower level for nonofluid compare to pure water. Moreover, it was observed that increase in nonofluid concentration results in increase of thermosyphon efficiency for all cases. The decrease in fill ratio increases the evaporator temperature due to reduction in contact of surface between the working fluid resulting in the heat transfer coefficient to be high. On the other hand, it also observed that lower efficiency at higher fill ratio shows that the rate of condensation is lower when the fill ratio is higher, which is parallel with findings of Kyung et al [3] where the efficiency is lower at higher fill ratio. However, their finding was in contrast that of Manimaran et al [14] that reported both the working fluid which was experimented shows higher efficiency as filled ratio increases. Thus, at lower fill ratio the advantage received by condenser section compensated by the reduction in performance in the evaporator section due to more dry out at lower fill ratio. Hence, it was also found out that at higher heat flux, there is no difference in efficiency with respect to fill ratio. This was due to higher heat flux that decreases the fluid level at evaporator section, which results in lower performance at the evaporator side.

Hamidreza et al [16] studied the thermal characteristics of a closed thermosyphon under various filling conditions. The experiment was carried out by varying the working fluid filled ratio at different heat inputs and the obtained results were then compared with numerical results from other studies. Based on their study it was found that the optimum filled thermosyphon has the shortest response time and the lowest thermal resistance. However, a slight increase in the input power will cause breakdown of the condensate film. The overfilled thermosyphon posed a slightly slower thermal response and greater thermal resistance compared to the optimal condition. Thus to ensure optimal and steady operation an optimum filled thermosyphon was recommended with a small amount of additional working fluid to prevent breakdown of the liquid film. Based on comparison of result made, it was noted that there are small differences in values obtain by the researcher. This is highly suspected due to differences of the possible heat loss from the evaporator end cap of the experiments. Eventhough based on the study it could be observed that increase in fill ratio at various heat input can contribute to a better performance, but it is clear that there is a limit for each system which leads the system not to perform further if exceeded. This findings are correlated to findings of Yong et al [11] that observed the thermosyphon performance is affected due to flooding limitations thus there is a limit to its performance.

Ong and Christopher [17] investigated the performance of water filled thermosyphons between 30 °C – 150 °C with length of 127 mm and inner and outer diameter of 34 mm and 50 mm. The experiment was carried out by studying the effect of condenser cooling rates at various fill ratios, inclination angles and aspect ratios. The result shows that that heat transfer coefficients increases with input power while overall thermal resistance decreases as fill ratio increases. Fig. 5 and 6 shows their findings.

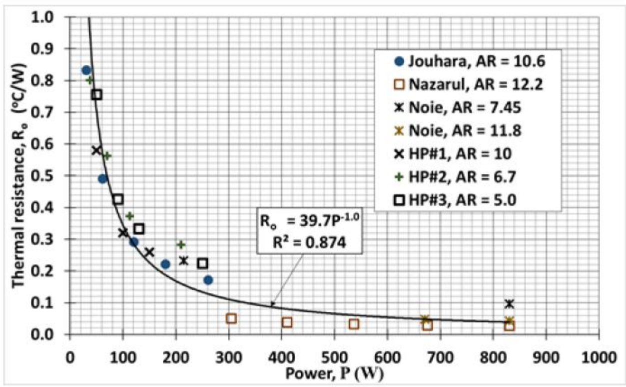

Fig.5 Thermal Resistance at Various Power Input Compared with other Researchers

Rahul and Pramod [18] studied the effects of working fluid, filling ratio and number of turns on pulsating heat pipe (PHP) thermal performance. The thermosyphon made of copper tube length of 262 mm and inner and outer diameter of 2 mm and 3.06 mm. The result show that thermal resistance for all working fluid pulsating heat pipes rapidly decreases with increasing heating power up to 32 W. In conclusion two turn pulsating heat pipe loop with methanol 50% volumetric filling ratio at more than 32 W heating power with one directional flow circulation is the optimum operating condition of present research. This is parallel with findings of Ong and Christopher [17] who observed that thermal resistance decreases as fill ratio increases. Their findings are shown on Fig. 7. Based on the finding from the

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studies made it's a clear cut that there will be significant effect on thermosyphon performance when there is increase in heat input.

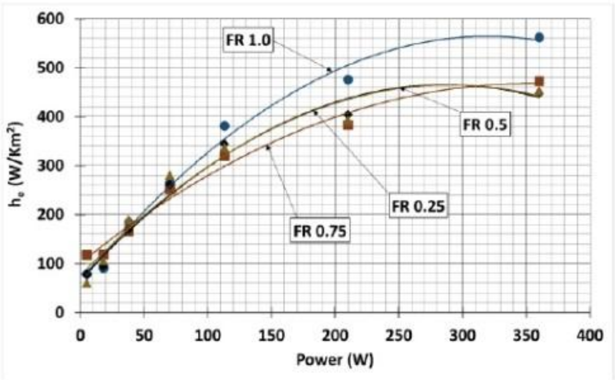

Fig.6 Heat Transfer Coefficient Increases with Input Power

Davoud Jafari et al [19] investigated the unsteady experimental and numerical analysis of a two-phase closed thermosyphon at different filling ratios with tube length of 500 mm and outer diameter of 35 mm. The experiment performed to determine the heat transfer rate and overall thermal resistance at range of 30–700 W and filling ratios of 16, 35 and 135 %. The result shows that the thermosyphon performance is better for filling ratio lower than 35 %. Fig.8 shows their findings. But at this filling ratio there are high risk of thermosyphon undergo dry-out effect which is parallel with findings of Ong et al [10] and Yong et al [11].

Alessandro Franco et al [20] did and experimental analysis on closed loop two phase thermosyphon with tube length of 155 mm by using different working fluids which are water and ethanol. The experiment carried out by analyzing both the working fluids by varying the heat input and operating pressure. Their finding was that both the working fluid performs differently as the heat load increases at different operating pressure, where ethanol found to perform better recommend at lower heat flow rates to compare to water. Thus, noted that different working fluid play a vital role as they have different physical properties that could affect the performance of the thermosyphon.

Zhen tong et al [21] investigated the effect of fill ratio on an R744 two-phase thermosyphon loop. The experiment was carried out to study the effect of different fill ratios on the working performance of two-phase thermosyphon loop with tube length of 1230 mm and inner and outer diameter of 6 mm. The result shows that at a low fill ratio the thermosyphon fluctuates under small heat loads. Whereas at fill ratio 100 % it reaches its maximum heat transfer ability, and when the fill ratio is around 62 % the lowest driving temperature difference is achieved.

Ong and Haider [22] studied the performance of performance of a R-134a-filled thermosyphon with tube length of 780 mm and thickness of 1.35 mm. The study was carried out to understand the effects of temperature difference between bath and condenser section, fill ratio and coolant mass flow rates on the performance of the thermosyphon. It is observed that heat transfer coefficient increases as the fill ratio and heat flux increases. Thus performance is lowest relatively at smaller fill ratio and heat flux. In conclusion the performance of the thermosyphon increases with increasing coolant mass flow rate, fill ratio and temperature difference between bath and condenser section. This is parallel with findings of Zhen tong et al [21] who observed under a lower fill ratio the thermosyphon performance more likely to fluctuate. Based on both the studies clearly it could be seen that they are similar effects on certain parameters although at usage of different working fluid.

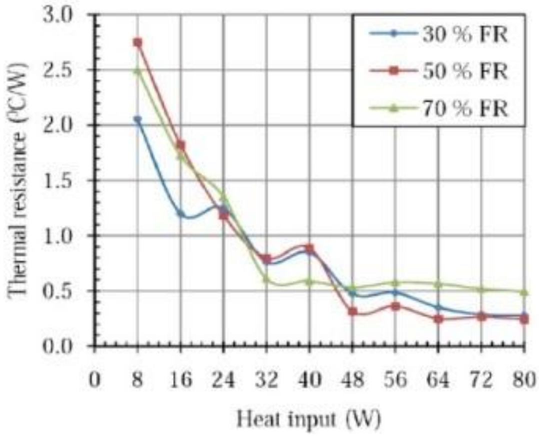

Fig.7 Thermal Resistance of PHP at different Filling Ratio

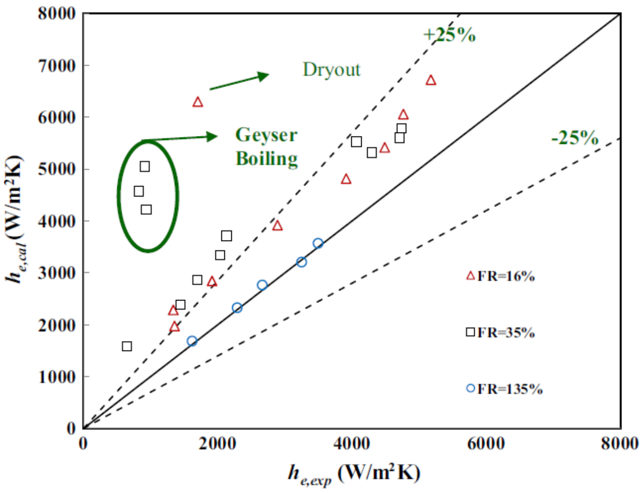

Fig.8 Evaporator and Condenser Heat Transfer Coefficient Comparison at varies Fill Ratio

Bandar Fadhl et al [23] studied the CFD modeling of a two-phase closed thermosyphon with tube length of 500 mm and outer diameter of 22 mm charged with R134a and R404a. The study was carried out by analyzing both the working fluids by varying the heat input and the obtain result were compared with the experimental values to verify the accuracy of the values obtain. It's a clear cut that temperature distribution through the thermosyphons is higher in CFD simulation to compare actual experimental values, which applies same operating conditions but it could be noted that both the compared result have a uniform temperature distribution curve. Fig. 9 and 10 showw their findings. Although both the experiment and CFD simulation was done with same parameters but still there

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is difference in the values obtain which shows that there are external factor which affect the accuracy of reading obtain from experimental value such as possible heat losses and method of controlling the temperature of the water bath at the evaporator section.

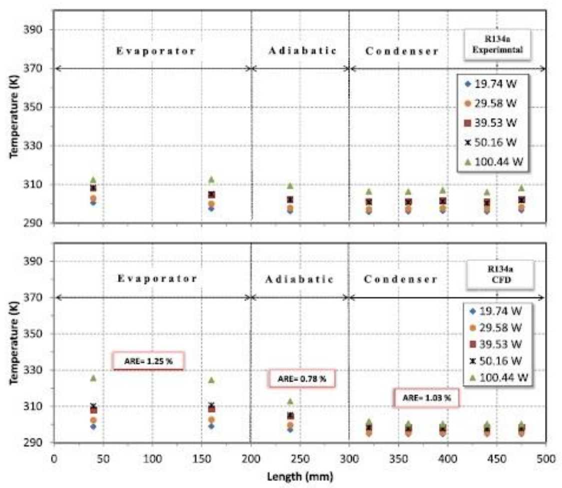

Fig.9 CFD Simulation Compared to Experimental Values Using R134a

Asghar et al [24] studied the gas/liquid two-phase flow and the CFD modeling simultaneous evaporation and condensation phenomena in a thermosyphon with tube length of 100 mm by using the volume of fluid (VOF) technique. The experiment conducted by varying the heat flow rates of 700 W, 500 W and 350 W at three different fill ratios .Results showed that increase in the inlet heat flow from 350 W to 500 W increases the thermosyphon's performance. However, applying higher energy to the evaporator decreases the performance. Moreover, it also determined that there is an optimum value of fill ratio for each value of input energy to the evaporation section, which is 0.5. Fig. 11 shows their findings.It was also note that increase in the thickness of liquid layer in the thermosyphon could cause higher thermal resistance and consequently lower the heat transfer coefficient. Next, it observed that the decrease in the capability of heat absorption in the condenser section could decrease the thermal efficiency of thermosyphon. Moreover, based on the comparison made a good agreement was observed between CFD predicted and measured temperature profiles. Fig. 12 shows their findings. Based on study of Bandar Fadhl et al [23] and Asghar et al [24] it could be noted that CFD is a useful tool to model and explains the complex flow and heat transfer in a thermosyphon.

Hussam Jouhara et al [25] studied the three-dimensional CFD simulation of geyser boiling in a two-phase closed thermosyphon with tube length of 100 mm and outer diameter of 12 mm. The study was done thus to verify the ability of CFD simulation to visualize the characteristics of geyser boiling. The CFD simulation results of this study show that FLUENT with the VOF and UDFs can successfully model the complex phenomena inside the wickless heat pipe. Thus, the CFD visualization results of this study have demonstrated the abilities of the CFD model to simulate the pool boiling behavior for different working fluid. Hence, this is a significant prove that CFD simulations could help to visualize and justify such studies.

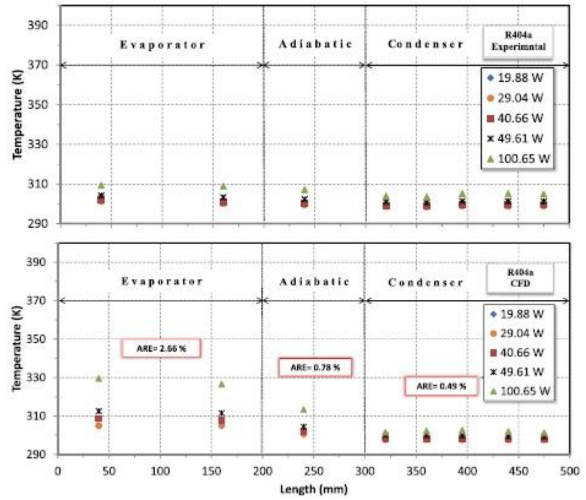

Fig.10 CFD Simulation Compared to Experimental Values Using R404a

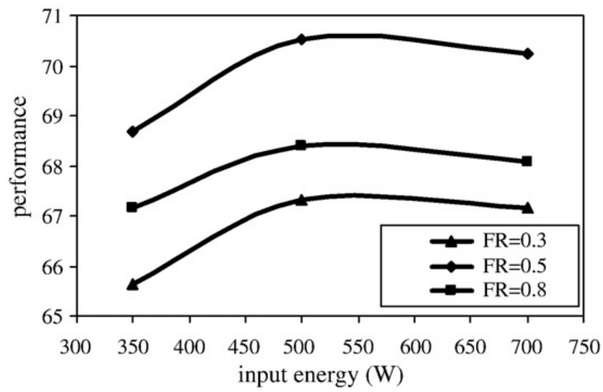

Fig.11 Thermosyphon Performances at Various Fill Ratios

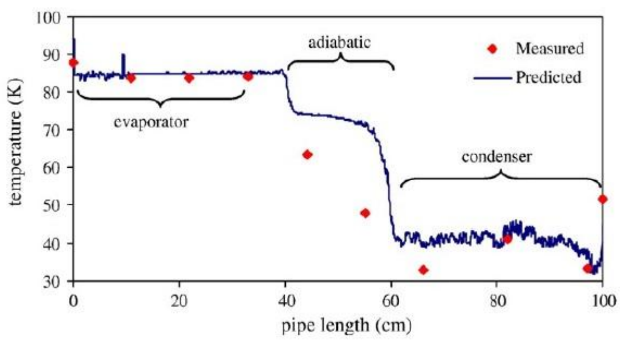

Fig.12 The Comparison between CFD Predicted and Measured Temperature

Noie [26] carried out experimental study of condensation and boiling heat transfer of a two phase closed thermosyphon with tube length of 500 mm and outer diameter of 33 mm. The heat transfer coefficient of thermosyphon compared with the existing correlations. The result obtained not as expected when comparing the experimental result of condensation heat transfer of

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the thermosyphon and Nusselt's correlation. Due to poor in consistency between the experimental results of the boiling heat transfer coefficient and existing correlations, the working condition were reanalyzed and a new practical formula (correlation) was derived. The new correlation can utilize to predict new boiling heat transfer coefficient. Hence, the practical formula (correlation) recommended by the researches as follow:

$$h_e = 4.7882 \times q^{0.6714} \times \left(p_{sat}\right)^{0.2565} \times (FR)^{0.0044} \times (AR)^{0.0287} \quad (2)$$

Based on the overall heat transfer coefficient obtained from the experimental results exhibited that the heat flux of the thermosyphon was nearly 250 times that of a copper rod with the same dimensions. In addition, the maximum heat transfer rate for each aspect ratio occurs at different fill ratio. For an aspect ratio of 9.8, the maximum heat transfer rate occurs when the filling ratio at 60%, while for an aspect ratio of 11.8, the highest value occurs at filling ratio of 30%.

Suchana et al [27] investigated effects of inclination angle on heat transfer characteristics of closed loop pulsating heat pipe with length of 1480 mm by using water and ethanol as working fluid at different inclination angles. The results show that input heat flux, inclination angle and physiochemical properties of the working fluid have significant effect on the thermal performance heat pipe, at where highest heat transfer was recorder at inclination angle of 75°.

Fajing Li et al [28] evaluated R404a ,R600a and R134a single loop thermosyphon for shaft cooling in motorized spindle tested at filling ratios of 30% to 80% and operating at evaporator temperature between 20 °C to 72 °C. The obtain result then compared with values obtain from refrigerants R134a and R600a. Results shows that at evaporating temperature below than 57 °C R404a single loop thermosyphon has higher heat transfer efficiency and smaller thermal resistance compare to R134a and R600a.

Robert et al [29] studied the global warming potential of a closed two-phase thermosyphon with length of 2200 mm for different working fluids. Five shortlisted potential replacement fluids was listed based on considering criteria's evolved the environmental, operating condition, storage conditions, and cost were selected for tests thermsyphons representatively. Based on the experimental result, water with 5 % ethylene glycol mixture is a suitable replacement fluid, although under certain criteria its performance is lesser than R134a. In addition, the tests also showed that water alone could provide the highest heat transfer, although it was not suitable to the target temperature range, and methanol did not perform as well as R134a for most of the experimental ranges. Thus findings of Fajing Li et al [27] and Robert, et al [28] show that that properties working fluid play a vital role as they have different properties that could affect the performance of the thermosyphon.

Engin Gedik [30] investigated the thermal performance of a two-phase closed thermosyphon at different operating conditions. The experiment is conducted by using water, ethanol, and ethylene glycol as the working fluids and to operate at different inclination angles, heat inputs and flow rates of cooling water The results show that water was the best working fluid when the heat inputs were 200 W and the flow rates of the cooling water were 10 L/h. Ethylene glycol was the best working fluid when the heat inputs were 200 W and the flow rates of the cooling water were 30 L/h. Ethanol was the best working fluid when the heat inputs were 600 W and the flow rates of the cooling water were 10 L/h. In addition, it was found that the inclination angle and heat inputs had significant effects on the efficiency of the TPCT.

I. Summary of Literature Survey Test Parameters

No	Researchers	Test Parameters
1	Amatachaya et al [2]	FR: 30-90 % AR:9.52-36.32 Heat flux: 6-18 kW/m^2
2	Kyung et al [3]	FR:37.5-167 % Power:25-1600 W
3	Hasna Louahlia et al [4]	FR:7.4-10.4% Power:50-450 W
4	Thanaphol and Naris [5]	Tilt angle : 15-75° Heat flux: 4.3-32.5 kWm^2
5	Khalid and Witwit [6]	Adiabatic varied length = 100,300 and700 mm Heat flux: 5 to 32 kWm^2
6	Anjankar and Yarasu [7]	Condenser varied length = 350,400 and 450 mm Power:300,500,700 W Flow rate :0.0027 kg/s
7	Brusly Solomon et al [8]	Heat flux: 25-250 kWm^2
8	Renjith Singh et al [9]	FR: 40%,60% ,100% Inclination angle : 0°,45° ,90° Power:50-300 W
9	Ong et al [10]	FR : 50%-100% Inclination angle : 30°,60° ,90° Power: 40-100 W Evaporator Temperature : 25-50°C
10	Yong et al [11]	Power: 50-600W FR:10-70%

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11	Payakaruk et al [12]	FR: 50,80 ,100 % AR:5,10,20,40 % Inclination angle:5°-90°
12	Ong et al [13]	FR_{Water}:25-93 % FR_{R410a}:25-100 % Inclination angle:30°,50°,70°,90°
13	Manimaran et al [14]	FR:25-100% Inclination angle : 0°-90°
14	Shanthi and Velraj [15]	FR:50,75,100 % Power: 115-230W
15	Hamidreza et al [16]	FR : 5-80 % Power : 200 W
16	Ong and Christopher [17]	FR:25-100 % Inclination angle:23°-90° AR:5-10% Power:5-405 W Flow rate: 0.003-0.005 kg/s
17	Rahul and Pramod [18]	FR:30,50,70% Power:32W
18	Davoud Jafari et al [19]	FR:16,35,135 % Power:30-700 W
19	Alessandro Franco et al [20]	Power:750 -1700 W
20	Zhen tong et al [21]	FR:45-151% Power:200-1700 W
21	Ong and Haider [22]	FR:80% Flow rate: 0.0121 kg/s P: 750 W
22	Bandar Fadhl et al [23]	FR:50% Power:50-500 W
23	Asghar et al [24]	FR:30,50,80% Power:350,500,700 W
24	Hussam Jouhara et al [25]	Operating Temperature :0-100°C
25	Noie [26]	FR:8-100% AR: 9.8-11.8 %
26	Suchana et al [27]	Inclination angle:0°, 30°,45°,60°,75° ,90°
27	Fajing Li et al [28]	FR:30-80% Power :20-200 W
28	Robert et al [29]	Operating range:-10°C-80°C
29	Engin Gedik [30]	Inclination angle : 30°,60° ,90° Power : 200,400,600 W Flow rate:0.003-0.008 kg/s

V. CONCLUSION

This paper presents the most recent stage in the development of thermosyphon from analytical, numerical and experimental perspectives. The two-phase thermosyphon could contribute decisive and effective thermal control for energy conservation, recovery and renewable applications. Many studies have been conducted experimentally, mathematically and computationally to identify the different factors affecting the thermal performance of thermosyphon. The following were concluded from their findings:

1. Properties of working fluid, filling ratio, geometry (distance across, shape and length), thermosyphon material properties and dimensions, length (evaporator, condenser and adiabatic section), aspect ratio, heat load, coolant temperature, inner pressure affect the thermal performance of thermosyphon.
2. Based on findings of Ong et al [10] and Payakaruk et al [12] it could see that filling ratio and inclination angle has very small influence on heat transfer. However, heat transfer performances are higher between inclination angles of 50° to 90°. Moreover circulation of working fluid in the thermosyphon completes due to effect of gravity. Therefore, thermosyphon unable to perform in horizontal position.
3. Increase in fill ratio at various heat input can contributed to a better thermosyphon performance, But it’s a clear cut that there is a limit for each system which cause the system not to performance further if it exceeded. That could observe from findings of Ong et al [10], Yong et al [11], Hamidreza et al [16], and, Davoud Jafari et al [19], Asghar et al [24] team findings. Nevertheless, dry out effect could easily occur in the case of high input power at low fill ratio, as it will cause an increase of evaporator side temperature due to reduction in contact surface with working fluid. Generally, filling ratio ranges between 45% to 65% show better heat transfer performance.
4. To achieve an effective heat transfer, the surface area of condenser section should be greater or equal to the surface area of evaporator section. Thus, such condition could achieve by altering diameter or length of evaporator, adiabatic and condenser sections. That could observe from findings of Thanaphol and Naris [5] and Khalid and Witwit [6] , Anjankar and Yarasu [7].
5. Working fluid plays a vital role as they have different physical properties that affect the thermal efficiency of the thermosyphon. Refrigerants

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show effective heat transfer performance for lower temperature span. That could be observing from findings of Fajing Li et al [28] and Robert, et al [29] team findings. Taking into account the effect of global warming due to the refrigerants having high global worming potential (GWP), it is mandatory to use and search new refrigerants having less GWP.

6. Different heating methods also play a role in achieving a better overall heat transfer coefficient, where that conventional heating method performs better as of larger heat transfer coefficient. That could be observing from findings of Amatachaya and Srimuang [2].
7. CFD is a very useful tool to justify and to explain the experimental results as simulation results will be more accurate compare to experimental results has it is not subject to heat loss phenomena. That observed from findings of Bandar Fadhl et al [23], Asghar, et al [24] and Hussam Jouhara et al [25].

NOMENCLATURE

AR	Aspect ratio
Bo	Bond number
d_i	Inner diameter (m)
d_o	Outer diameter (m)
FR	Filling ratio
h_e	heat transfer coefficient for evaporator ($W/m^2.K$)
h_c	heat transfer coefficient for condenser ($W/m^2.K$)
Ku	Kutateladze number
P_{sat}	Saturated pressure (Pa)
Q	Heat transferred (J)
Q_{90}	Heat transfer by thermosyphon at 90° (J)
q	Heat flux (W/m^2)

ABBREVIATION

CFD	Computational fluid dynamics
CTPCT	Conventional two-phase closed thermosyphon
FTPCT	Flat two-phase closed thermosyphon
GWP	Global warming potential
PHP	Pulsating heat pipe
TPT	Two-phase thermosyphon
TPCT	Two phases closed
UDF	User define function
VOF	Volume of fluid

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