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TWO PHASE THERMOSYPHON – A REVIEW OF STUDIES

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ABSTRACT

The use of the two-phase thermosyphons (TPTs) is increasing for many heat transfer applications. This paper reviews the most recent published experimental and theoretical studies on the TPTs. The influence of the affecting parameters on the performance of TPTs such as the geometry (diameter, shape and length), the inclination angle, the filling ratio (FR), the working fluid, the operating temperature and pressure analyzed by various researchers is discussed. The various operating limits occurring in a thermosyphon includes viscous, sonic, dryout, boiling and flooding are also analyzed. Considering the application of TPTs, this paper presents a review of experimental tests. This paper can be used as the starting point for the researcher interested in the TPTs and their renewable energy applications.

KEYWORDS: Filling Ratio, Heat Transfer Coefficient, Inclination Angle, Two Phase Thermosyphon

INTRODUCTION

Two phase thermosyphons are enclosed heat transfer devices. They work on efficient heat transport process of evaporation and condensation to maximize the thermal conductance between a heat source and a heat sink. They are often referred as thermal superconductors because they can transfer large amounts of heat over relatively large distances with small temperature difference between the heat source and heat sink. The amount of heat that can be transported by these devices is usually several orders of magnitude greater than pure conduction through a solid metal rod of same dimensions[10]. They are proven to be very effective, low cost and reliable heat transfer devices for applications in many thermal management and heat recovery systems. The TPT technology has found increasing interest of the researchers in a wide range of applications from small-scale to large-scale systems.TPTs are used in chemical and petroleum industries , electronic cooling, telecommunication devices, energy storage systems, the railway transportation systems, thermoelectric power generators,seasonal cooling, load reduction of buildings, cooling of super conducting bearings. TPTs can be also used for thermal control of solar energy based systems.

WORKING PRINCIPLE

A two-phase closed thermosyphon is a highly efficient heat transfer device. It employs the principle of evaporation and condensation of the working fluid. It is a closed tube filled with a small amount of a working fluid (Figure 1). In such a device, heat is supplied to the evaporator wall, which causes the liquid in the pool to evaporate. The generated vapor then moves upwards to the condenser. The heat transported is then rejected into the heat sink by a condensation process. The condensate forms a liquid film which flows downwards due to gravity.

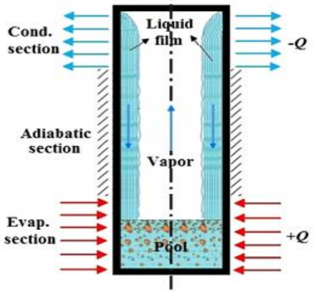

Fig 1: Two phase thermosyphon

FACTORS AFFECTING THE THERMAL PERFORMANCE OF THERMOSYPHON

From the literature survey, it is observed that following factors affects the thermal performance of two phase thermosyphon.

1. Properties of working fluid
2. Filling ratio
3. Coolant flow rate
4. Coolant temperature
5. Heat load
6. Inside pressure of thermosyphon
7. Thermosyphon material properties and dimensions
8. Length of various sections (evaporator section, adiabatic section and condenser section).

REVIEW OF WORK CARRIED OUT

Many investigations were carried out in order to analyse the thermal performance of two phase thermosyphon. Y.Lee and U. Mital [1] have carried out an experimental study on the heat transfer performance of a two-phase closed thermosyphon. Water and Freon-11 were used as the working fluids. Out of many possible controlling variables, the effects of the amount of working fluid in the tube, the ratio of heated-length to cooled length, the operating pressure, the heat flux and the working fluid were investigated. The thermosyphon test tube used in the present study was made of a 1 inch standard copper tube. The tube was 54 inch long and 1.062 inch internal diameter with a wall thickness of 0.127 inch. Twelve iron-constantan thermocouples, insulated with magnesia were sheathed in stainless steel tube of 1.189 inch outer diameter. The heaters were made of 15 AWG Chromel-A Nichrome wire with ceramic beads strung on it. Electrical power was supplied from a variable transformer rated at 13.4 KVA, 240V. Results show that the maximum heat transfer coefficient increases with decrease in the heated length to cooled length ratio, The heat transfer coefficient increases appreciably with an increase in the mean operating pressure inside the thermosyphon. The maximum heat transfer coefficient with Freon-11 was small compared to that of water.

H. Nguyen and M.Groll [2] have investigated heat transport limitations of two phase thermosyphon. Experiments with copper-water thermosyphon of 2.5 m length and 20 mm outer diameter were carried out. Steady state operation has been studied and maximum performance due to flooding has been measured. The influence of liquid fill charge, inclination angle and operating temperature has been studied. It was found that influence of fill charge exerts small influence on heat transfer and influence is more pronounced for greater inclination angles. Maximum heat transfer occurs for inclinaton angle between 40° to 60°.

H. Imura, K. Sasaguci and H. Kozai [3] have carried out experimental study on critical heat flux in a closed two-phase thermosyphon. The effects of inside diameter, heated length, working liquid, fill charge and inside temperature on the critical heat flux were investigated. The present experimental data were correlated with expressions already proposed by other investigators but the agreements were not good. Accordingly, a new correlating expression was derived. This expression agrees with the experimental data within ± 30% accuracy. Also, discussion of the adequate fill charge was made.

Charles C. J. Vincent and Jim B. W. Kok [4] have investigated transient response of industrial two-phase closed loop thermosyphon. The control volume approach is the base of a global analysis describing the motion of vapor and liquid phases of the thermosyphon system in one-dimensional equations. Interfacial shear forces were neglected as only co-current flows were present. Heat transfer coefficients were based on empirical correlations. It is found that the density ratio of vapor to liquid, dimensionless friction coefficient and water column length determine respectively the overall dynamic behavior characteristics such as response time, damping and oscillation frequency. Common industrial conditions are high operating temperatures up to 280°C, water as working liquid, power supply of 1-2 MW and a liquid filling of 0.31 m^3. The evaporator pipes were flooded to prevent local overheating. The heat source was a boiler, the heat sink was a tray of liquid, for example vegetable oil. In the condenser, the vapor flow is divided over several heat coils. The evaporator consists of an assembly of vertical pipes. As the total cross-section of the evaporator was larger than that of the condenser, a small change of water elevation in the evaporator causes a large change of water elevation in the condenser.

Khalid A. Joudiand A.M. Witwit [5] have investigated the performance of conventional two phase thermosyphon and modified thermosyphon with a separator in the adiabatic section . Two phase thermosyphons with a three layered wick in the evaporator section, in addition to the separator, were investigated. All two phase thermosyphons in this investigation were manufactured from copper tubes of 20 mm internal diameter, having a wall thickness of 1 mm. The evaporator and condenser lengths were kept constant for all two phase thermosyphons at 100 and 150 mm lengths, respectively. The adiabatic section length was varied at 100, 300 and 700 mm.The performance of the modified two phase thermosyphons was compared to a conventional two phase thermosyphon. The effect of varying the adiabatic length was, thus, investigated distinctly in conventional two phase thermosyphon and in modified two phase thermosyphons with a separator. Water was employed as the working fluid in two phase thermosyphons. The experimental program included five inclination angles and a heat flux range from 5 to 3 kW/m^2. The presence of the adiabatic separator caused a marked improvement in all two phase thermosyphons tested for all lengths and inclination angles. Results show that the presence of the adiabatic separator resulted in a marked increase in heat transfer coefficient over other two phase thermosyphons. The average increase is approximately 35%. The introduction of the adiabatic separator lowered the working temperature and eliminated the effect of inclination angles above 45°, while the addition of the screen wick and separator eliminated the effect of inclination angle but, in turn, increased the wall temperature, thus reducing it's efficiency.

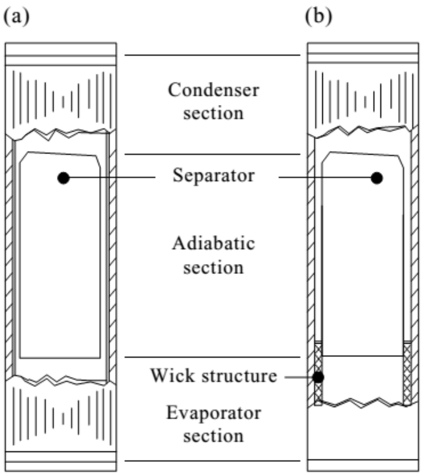

Fig 3: Two phase thermosyphon without wick structure (a) and with wick structure (b)[5]

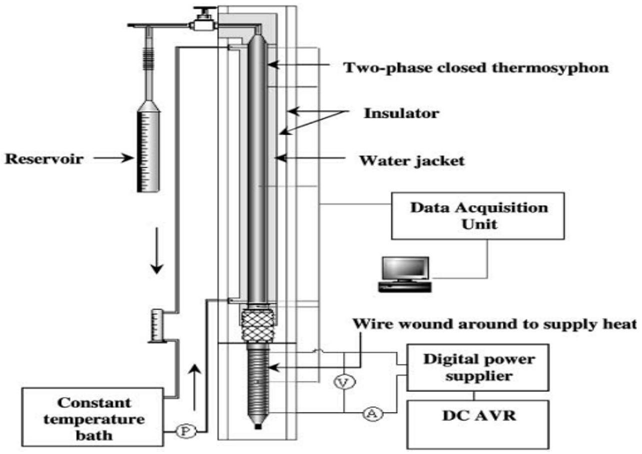

Fig 4: Schematic of experimental set up [6]

Yong Joo Park, Hwan Kook Kang and Chul Ju Kim[6] have investigated the heat transfer characteristics of a two-phase closed thermosyphon at various filling ratios. For the test, a two-phase closed thermosyphon (copper tube, FC-72 (C_6F_{14}) as working fluid) was fabricated with a reservoir which could change the fill charge ratio. The experiments were performed in the range of 50–600 W heat flow rate and 10–70% filling ratio. The effect of filling ratio on heat transfer coefficient of the evaporator was nearly negligible. However at the condenser, the heat transfer coefficients showed some enhancement with the increase of filling ratio by the expanded working fluid pool and the heat transport limitations appeared in different ways to the filling ratio. For the relatively small filling ratio (< 20%), it occurred by the dry-out limitation with maximum heat flow rate of 100 W. For the large filling ratio, it occurred by the flooding limitation and the maximum heat flow rate was about 500–550 W for bond number Bo: 26 to 28 and 230 W for bond number Bo: 18.3 respectively.

Rahmatollah Khodabandeh and Bjorn Palm [7] investigated the influence of system pressure on the boiling heat transfer coefficient in a closed two-phase thermosyphon loop. The setup used in this study consists of a thermosyphon loop, including evaporator, condenser, downcomer and riser. The loop has three evaporators, connected in parallel, made from small blocks of copper(10× 20 × 15) mm in which five vertical channels with diameters 1.5 mm and length 15 mm were drilled. Experimental results in terms of heat transfer coefficients at different system pressures and heat inputs were presented and compared to predictions of correlations from the literature. In all tests, isobutane was used as working fluid. Effect of input heat flux on temperature difference (T_W-T_{sat}) for isobutene is given in fig. 5 for reduced pressure P_r =0.3 and P_r = 0.02 (P_r = P/P_{cr}). Effect of reduced pressure P_r on heat transfer coefficient for P_t(heat deccipated by thermosyphon)= 99.5 to 106.4 is given in fig 6

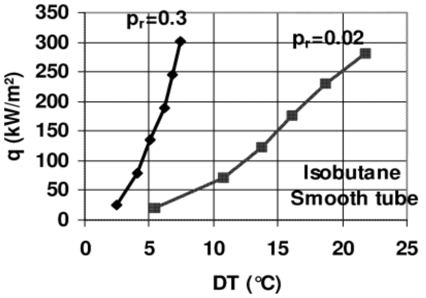

Fig 5: Heat flux Vs difference in temperature [7]

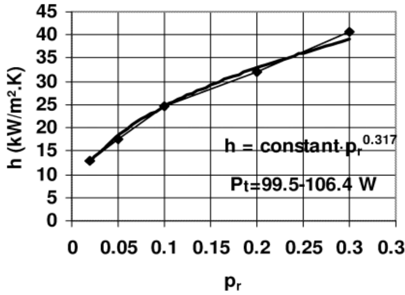

Fig 6: Heat transfer coefficient Vs reduced pressure[7]

Mao-Ching Lin, Lin-Jye Chun , Wen-Shing Lee and Sih-Li Chen [8] investigated two phase thermosyphon energy storage system. They fabricated an energy storage system, which can be readily integrated with the building structure. It stores heat supplied by solar energy via the two-phase closed loop thermosyphon to storage tank and releases stored heat in energy storage material via two-phase closed thermosyphon to the heat exchanger through the flow of transport fluid.The functions of such energy storage system have three operating modes, i.e., heat charge, heat discharge, and simultaneous charge and discharge. The thermal performance of the system with alcohol and water as working fluid was experimentally investigated. The result shows that the storage system employing alcohol as working fluid in the loop thermosyphon provides better performance. The system has given optimum heat charge and discharge performance under 35–40% filling ratio, regardless whether the working fluid is water or alcohol. The system displays optimum charge efficiency of 73% and optimum discharge efficiency of 85% with alcohol as working fluid.

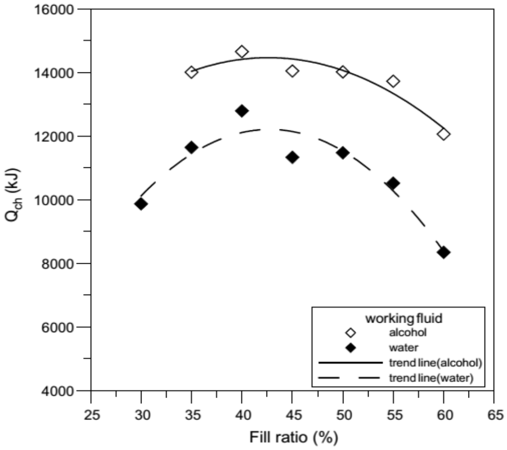

Fig 7: Compaison of stored energy under different working fluid and fill ratio [8]

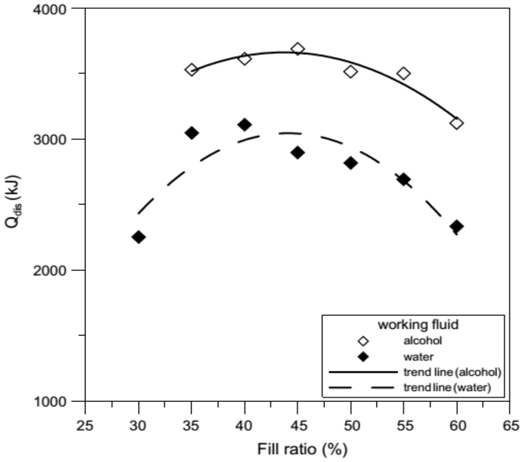

Fig 8 : Compaison of heat discharged under different working fluid and fill ratio [8]

Rahmatollah Khodabandeh[9] investigated thermal performance of a closed advanced two-phase thermosyphon loop for cooling of radio base stations at different operating conditions. In this investigation, an advanced thermosyphon loop with extended evaporator and condenser surfaces has been tested at high heat fluxes. The thermosyphon investigated was designed for the cooling of three parallel high heat flux electronic components.The tested evaporators were made from small blocks of copper in which five vertical channels with a diameter of 1.5 mm and length of 14.6 mm were drilled. The riser and downcomer connected the evaporators to the condenser, which was an air-cooled roll-bond type with a total surface area of 1.5 m^2 on the air side. Tests were done with isobutane at heat loads in the range of 10–90 W to each of the components with forced convection condenser cooling and with natural convection with heat loads of 10–70 W. Variation of overall heat transfer coefficient for forced and natural convection is shown in fig 9

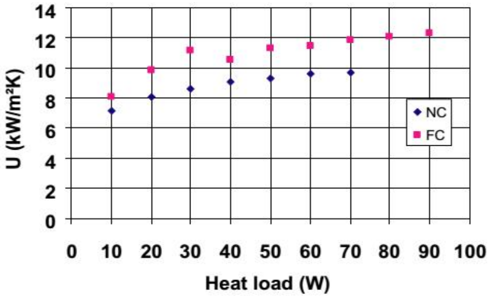

Fig 9: Overall heat transfer coefficient for forced(FC) and natural convection(NC) [9]

S. H. Noie [10] has carried out experimental investigation of boiling and condensation heat transfer of a two phase closed thermosyphon. Heat transfer coefficients inside the thermosyphon were compared with the existing correlations. A good agreement between the experimental results of condensation heat transfer of the thermosyphon and nusselt's correlation was obtained. In addition, the optimal working fluid filling and the overall heat transfer coefficient were evaluated for practical operation. Finally, according to poor agreement between the experimental results of boiling heat transfer coefficient and existing correlations, the working conditions were analyzed and a new practical formula (correlation) was presented. The new correlation can be used to predict boiling heat transfer coefficient. The working conditions have been analyzed and a new practical formula (correlation) was recommended as follow:

$$h_e = 4.7882 \times q^{0.6714} \times (\, p_{sat})^{0.2565} \times (F.R)^{0.0044} \times (A.R)^{0.0287}$$

Experimental values of the overall heat transfer coefficient showed that the heat flux of the thermosyphon was nearly 250 times that of a copper rod with the same dimensions. Maximum heat transfer rates for each aspect ratio occurred at different filling ratios. For an aspect ratio of 9.8, the maximum heat transfer rate occurs when the filling ratio was 60%, while for an aspect ratio of 11.8, the highest value occurs at filling ratio of 30%.

T. Payakaruk, P. Terdtoon and S. Ritthidech [11] carried out experiments to predict heat transfer characteristics of an inclined closed two-phase thermosyphon at normal operating conditions. The parameters studied were Bond numbers, Froude numbers, Weber numbers and Kutateladze numbers, and experiments were conducted to find out their effects on the heat transfer rate and on the total thermal resistance. Copper thermosyphons with an ID of 7.5, 11.1 and 25.4 mm were employed with R22, R123, R134a, ethanol, and water as the working fluids. The selected filling ratios were 50, 80, and 100% and the selected aspect ratios were 5, 10, 20, 30 and 40 respectively. Experiments were conducted by varying the inclination angle from the horizontal axis by 5°,10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90° and the controlled vapor temperature range from 0°C to 30 °C. It was found from the experiments that, the filling ratio has no considerable effect on heat transfer characteristics at any angle. But the properties of the working fluid effected the heat transfer characteristic. Results show that, lower the latent heat of vaporization, higher the Q/Q_{90}. After further consideration it was found that a correlation could be established between Q/Q_{90} and the modifed Ku, The correlation is as follow:

$$Q/Q_{90} = 1.678\ Ku^{*0.0196}$$

Rahmatollah Khodabandeh [12] has investigated the influence of heat flux, system pressure, mass flow rate, vapor fraction, diameter of evaporator channel and tubing distance between evaporator and condenser on the heat transfer coefficient of an advanced two phase thermosyphon loop. The tested evaporators were made from small blocks of copper with 7, 5, 4, 3 and 2 vertical channels with the diameters of 1.1, 1.5, 1.9, 2.5, and 3.5 mm, respectively and the length of 14.6 mm. Tests were done with isobutane at heat fluxes ranging between 28.3 to 311.5 kW/m^2. It was found that the heat transfer is weakly dependent on vapor fraction but highly dependent on heat flux and system pressure, indicating that nucleate boiling is the dominant mechanism.

Sameer Khandekar and Balkrishna Mehta [13] have investigated two phase closed thermosyphon with nano fluids. Nanofluids, stabilized suspensions of nanoparticles typically < 100 nm in conventional fluids, are evolving as potential enhanced heat transfer fluids due to their better thermal conductivity, increase in single phase heat transfer coefficient and significant increase in critical boiling heat flux. They investigated the overall thermal resistance of a closed two-phase thermosyphon using pure water and various water based nanofluids (Al_2O_3, CuO and Laponite clay) as working fluids. They observed that all these nanofluids show inferior thermal performance than pure water. Further more, it was observed that the wettability of all nanofluids on copper substrate, having the same average roughness as that of the thermosyphon container pipe, is better than that of pure water as shown in fig. 10

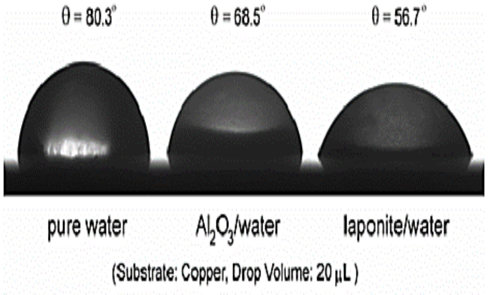

Fig10: Contact angles for different fluids[13]

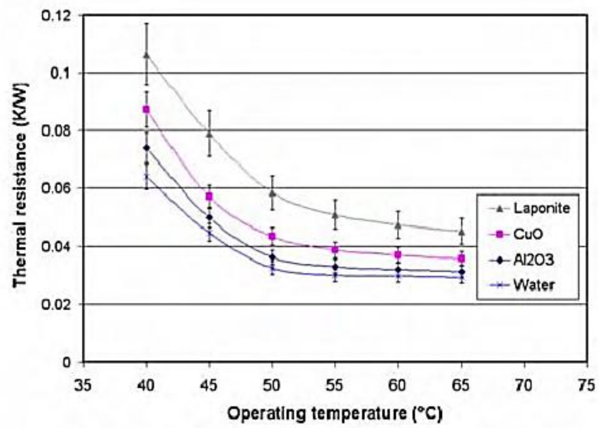

Fig 11: Thermal resistance Vs operating temperature [13]

H. Mirshahi and M. Rahimi [14] have investigated effect of heat loads, fill ratio and extra volume on performance of a partial-vacuumed thermosyphon. A rig was made from a 1 m copper tube with an inner and outer diameter of 17.5 and 19 mm. The heights of the evaporator, the adiabatic section and the condenser were 40, 20 and 40 cm, respectively. The temperatures at different places on the thermosyphon and on the inlet/outlet of the cooling water were measured. It was observed that change in heat flux, fill ratio and employing different extra volumes, has a significant effect on its performance. It was found that as extra volume increases, surface temperature as well as performance of thermosyphon decreases. Maximum efficiency obtainened was 81 %

S.H. Noie, S. Zeinali Heris, M. Kahani and S.M. Nowee [15] have carried out experiments for heat transfer enhancement using Al_2O_3/water nanofluid in a two-phase closed thermosyphon. Nanofluids of aqueous Al_2O_3 nanoparticles suspensions were prepared in various volume concentration from 1–3% and used as working media. Experimental results show that for different input powers, the efficiency of the thermosyphon increases up to 14.7% when Al_2O_3/water nanofluid was used instead of pure water. Temperature distributions confirmed these results too.

Asghar Alizadehdakhel, Masoud Rahimi and Ammar Abdulaziz Alsairafi[16] have carried out CFD modeling of flow and heat transfer in a thermosyphon. In the present study a gas/liquid two-phase flow and the simultaneous evaporation and condensation phenomena in a thermosyphon was modeled. The volume of fluid (VOF) technique was used to model the interaction between these phases. Experiments in a thermosyphon were carried out at different operating conditions. The CFD predicted temperature profile in the thermosyphon was compared with experimental measurements and a good agreement was observed. It was concluded that CFD is a useful tool to model and explain the complex flow and heat transfer in a thermosyphon.

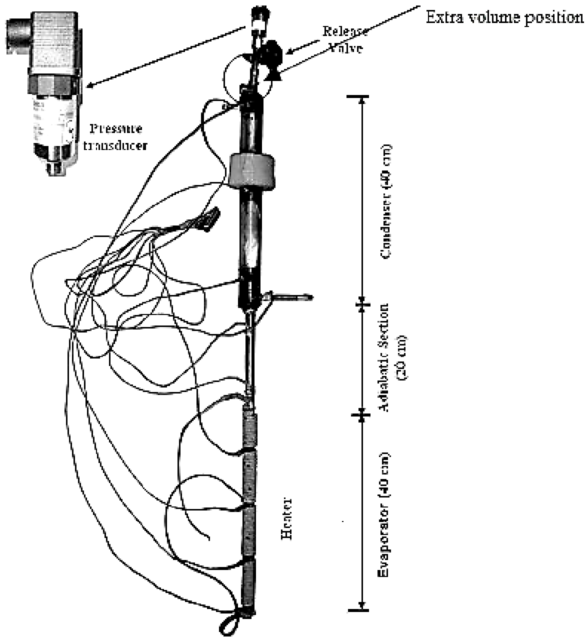

Fig 12: Two phase thermosyphon [15]

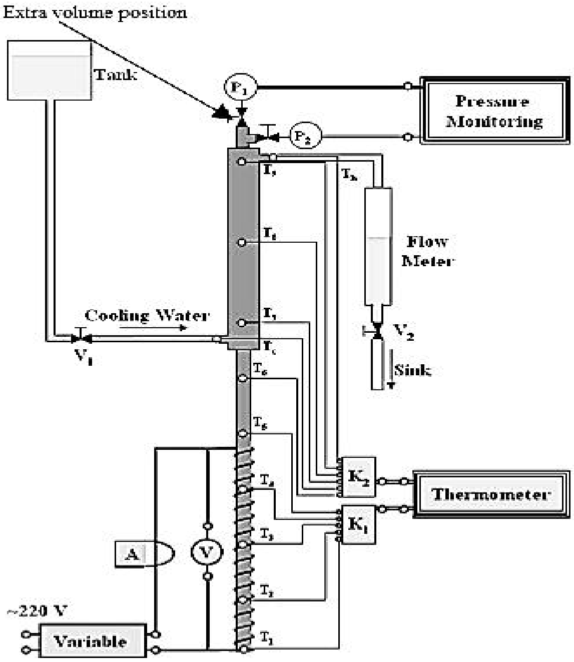

Fig 13: Schematic of experimental set up [15]

R.T. Dobsonl and D.G. Kriiger [17] have carried out experiments on an ammonia-charged two-phase closed thermosyphon. The tested thermosyphon was 6.2 m long and has internal diameter of 31.9 mm and was made of grade 304 stainless steel. Hot water up to 80°C and cooling water between 10°C and 20° C, inclination angles of 30°, 45°, 60°, 75° and 90° to the horizontal, evaporator to total length ratios of 0.06 to 0.33 and liquid charge fill ratio between between 20 to 100 were considered. Experimentally determined correlations did not correspond well with existing correlations. The heat transfer coefficient between the heating water and the outside surface of the thermosyphon (for evaporator) for a 400 mm long water jacket was experimentally determined as

$$h_e = 4.533\ Re_{hw}^{0.733}\ Pr_{hw}^{0.3626}$$

and heat transfer coefficient from the outside surface of thermosyphon to the cooling water was given as

$$h_c = 2.019\ Re_{hw}^{0.8089}\ Pr_{hw}^{0.3774}$$

The thermal conductivity of stainless steel is relatively sensitive to temperature changes and hence its thermal conductivity was determined as a function of wall temperature as

$$K_s = 9 + 0.02(T_w + 273.15)$$

The variation of the predicted evaporator heat transfer coefficient from experimentally deterrnined values was ±30% and for condenser, it was ±15%

Dr. Hussain H. Ahmad and Anwar A. Yousif [18] have compared heat pipe and a thermosyphon performance with variable evaporator length.The two systems were designed and constructed to investigate the performance and the affecting parameters,using ethanol as a working fluid. The affecting parameters studied were power input ($200 \leq Q \leq 700$ W), working fluid filling ratio (35% and 85%), aspect ratio and the ratio of evaporator length to inner diameter (4.0, 7.8 and11.5) . The experimental results showed that the best performance of heat pipe obtained at aspect ratio 7.8 and 85% filling ratio at 500 W where the maximum heat transfer coefficient was 9950 W/m^{2}K, while for the two phase thermosyphon, the best performance was obtained at aspect ratio 4.0 for 35% filling ratio and power input 600 W with maximum heat transfer coefficient equals to 4590 W/m^{2}K. The overall comparison between the two systems showed that the performance of the heat pipe is better than that of the two phase thermosyphon. The experimental results of heat pipe was compared with theoretical and empirical correlations showing reasonable agreement especially with Immura within 70%.

P.G.Anjankar and Dr.R.B.Yarasu [19] have carried out experimental analysis of condenser length effect on the performance of thermosyphon. Thermal performance of a vertical two phase closed thermosyphon with different flow rate to condenser and different heat input to evaporator with different condenser lengths has been investigated experimentally. Three lengths of condenser 450mm, 400mm, 350mm have been tried out. It was found that the thermal performance of thermosyphon at flow rate 0.0027 kg/s and heat input 500 W with condenser length of 450 mm is higher and the performance for 450mm condenser length is maximum than that of 400mm and 350mm condenser lengths for all the flow rates. It was concluded that condenser section length should be 1.5 times to that of evaporator length to get good thermal performance. It can be seen from fig 14 that at 500 W input heat and 10 liter per hour flow rate at 450 condenser length thermosyphon efficiency is highest. Due to leakage problem at higher flow rate, those are adjusted to 6, 8, 10 liter per hour, out of which 10 liter per hour give the highest performance.

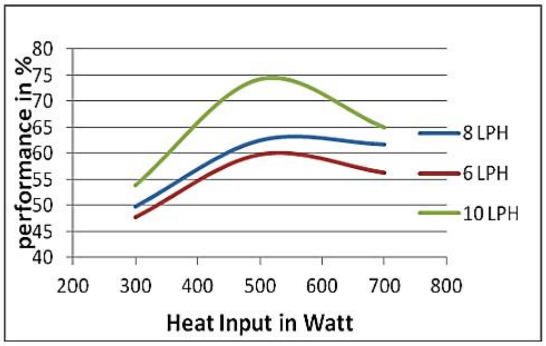

Fig 14: Performance at different heat input and cooling water flow rate [19]

Robert W. Mac Gregor, Peter A. Kew and David A. Reay [20] have investigated low global warming potential working fluids for a closed two-phase thermosyphon. They examined two-phase thermosyphons of length 2200 mm and external diameter 15.9 mm.. The work was prompted by the fact that R134a, used in similar units, will be subject to a ban in the future as it has a high Global Warming Potential. A shortlist of potential replacement fluids was drawn up, and considering the environmental, operating and storage conditions, and cost, five were selected for tests in representative thermosyphons.The results of the experimental work confirmed that water with 5% ethylene glycol mixture is a suitable replacement fluid, although under certain conditions it's performance was less than that of R134a. The tests also showed that water alone can give the highest heat transfer, although it was not suited to the target temperature range, and methanol did not perform as well as R134a for most of the experimental range.

M. Karthikeyan, S. Vaidyanathanand B. Sivaraman [21] have tested two phase thermosyphon with aqueous solution of n-butanol. Two copper thermosyphons of length 1000 mm, inner diameter 17 mm and outer diameter 19 mm were designed. Both were charged with 60 ml of working fluid with an evaporator length of 400 mm and condenser length of 450mm. One thermosyphon is charged with de-ionized water (DI) and the other with aqueous solution of n-butanol. It is found that the heat transfer coefficient of aqueous solution of n-butanol is higher than that of de-ionized water.

Ahmadou Samba, Hasna Louahlia-Gualous , Stephane Le Masson and David Norterhauser [22] have investigated two-phase thermosyphon loop for cooling outdoor telecommunication equipments. Transient and steady state analysis of the thermosyphon loop efficiency, the temperature distributions, the thermal resistance, and mass flow rate and heat losses by convection in the walls of cabinet as a function of heat load were studied.The n-pentane was used as the working fluid. Moreover, different working fluid filling ratios were tested and the results showed that the optimal filling ratio is about 9.2%. It was found that the maximum heat load of the telecommunication equipment was limited about 250 W for the traditional cooling system, while it was about 600 W for the thermosyphon loop cooling system.This result confirms that this cooling system is very attractive.

Yogesh S. Gandal and Vinayak M. Kale [23] have compared performance of two phase thermosyphon with different fluids and filling ratios. For the experimentation purpose four copper thermosyphons of same dimensions were designed and filled with aqueous solution of Propylene Glycol (PG) with 50% purity and De-ionized (DI) water with filling ratio of 40% and 60% and were heated with hot water in evaporator jacket from 60°C to 90°C.Thermosyphons were also tested for the inclination of 0° to 50° from vertical. Temperature distributions along the length of thermosyphons were noted, heat supplied to evaporator along with heat removed from condenser section were also measured. The experimental results indicate that the PG thermosyphon works better at higher heat inputs and it's optimum inclination angle was between 20° to 30° and that for DI water thermosyphon, it was 10° to 20°. Efficiencies of thermosyphons were found to increase with respect to increasing heat input but are less affected with filling ratios.

Majid Lotfi, Rasool Ghasemzadeh, Ali Kargar, and Rezvan Behfar[24] have calculated heat losses from evaporator and condenser section of two phase thermosyphon.Thermosyphon tested was a copper tube with inner diameter of 19.2mm and outer diameter of 22mm and length of 620mm . Convective heat loss in the condenser section was small that can be ignored. The rate of heat loss from insulated outer walls of the evaporator section from both convection and radiation was 3.5% of the input energy from electrical heater.

Marcin Lecki and Grzegorz Gorecki [25] have developed Computer Aided Engineering (CAE) program for prediction of two-phase closed thermosyphon throughput. Thermosyphon working fluids under consideration were modern refrigerants (R404a, R407c, R134a etc.). Program was cross-platform and written in Java language. Solution process of temperatures and heat flux was done by iterative scheme. Throughput and mean temperatures computed were compared with experimental data and found in good agreement.

I. Khazaee [26] has investigated heat transfer coefficient of two phase thermosyphon and developed a new co-relation for heat transfer coefficient for evaporator section as shown below. In these experiments two copper tubes of 1000 mm length with inside diameter of 15 and 25 mm and 2mm thickness were employed. An electrical resistance of 1000 W was employed to produce the heat input of evaporator and the accuracy of monitoring for voltage and electrical current was ± 2 % .Ethanol was used as working fluid.

$$h_e = 8.09 \, \frac{{k_l}^{1.59} \sigma^{1.09} {\rho_l}^{0.66} q^{0.94}}{{h_{fg}}^{0.94} (\rho_l - \rho_v)^{1.09} {C_p}^{0.59} {\mu_l}^{3.77} g^{1.09}}$$

Hamidreza Shabgard, Bin Xiao , Amir Faghri , Ramesh Gupta and Walter Weissman [27] have developed two-dimensional numerical model to simulate the transient operation of a thermosyphon with various working fluid filling ratios. Conservation equations for mass, momentum, and thermal energy were solved using finite volume scheme to determine the hydrodynamic and thermal behavior of the thermosyphon. The numerical model was validated through comparison with experimental data available in the literature.. Simulation results show that the evaporator temperature of the under filled thermosyphon rises dramatically due to dryout. The optimally-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 shows a slightly slower thermal response and greater thermal resistance compared to the optimal condition. To ensure optimal and stable steady-state operation, an optimally-filled thermosyphon was recommended with a small amount of additional working fluid to prevent breakdown of the liquid film.

M. Kannan, B. Deepanraj and A. Santhoshkumar [28] have tested two phase closed thermosyphon charged with different working fluids. Two phase closed thermosyphon was investigated experimentally for various filling ratio from 30% to 90% and with various operating temperature range from 30°C to 70°C in heat input range of 0 to 1200W.Copper tube of 1000mm length with 6.7mm inside diameter and 8mm outside diameter was employed. A series of experiment were carried out to investigate the maximum heat transfer capabilities of water,ethanol and methanol. It was found that maximum heat transport capability of water is high compared to that of other working fluids such as ethanol, methanol and acetone due to high specific heat capacity as shown fig. 15 and fig. 16

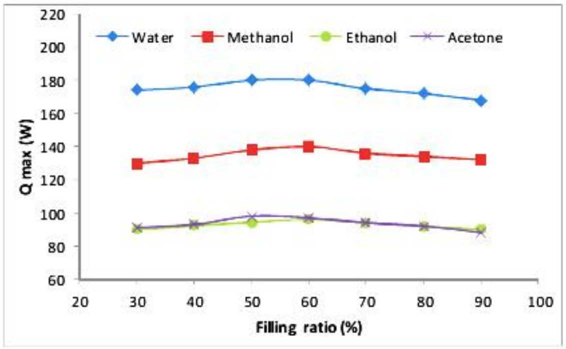

Fig 15 : Maximum heat transport capacity Vs filling ratio for operating temperature of 30°C [28]

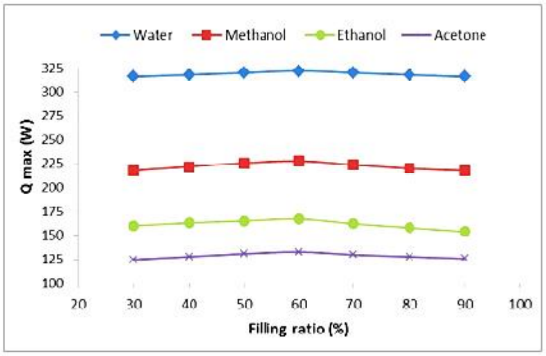

Fig 16 : Maximum heat transport capacity Vs filling ratio for operating temperature of 70°C [28]

R. Senthil, M. Kannan, R. Baskaran and B. Deepanraj [29] have conducted experiments with three different thermosyphons with inner diameters of 6.7, 9.5 and 12 mm. The variation of heat transport capability of the thermosyphon was studied for the input heat transfer rate ranging from 0 to 1200 W for various filling ratios and with operating temperature from 30°C to 70°C. Water, methanol, ethanol and acetone were used as working fluids. The maximum heat transport capability was found to be high for water compared to other fluids such as ethanol, methanol and acetone at the operating temperatures higher than 40°C.

CONCLUSION

This paper presents the state of the art of two phase thermosyphon from different points of view: analytical, numerical and experimental.Two phase thermosyphon can provide reliable and effective thermal control for energy conservation, energy recovery and renewable energy applications. Researchers have done experimental, mathematical and computational investigation to find out various factors affecting the thermal performance of thermosyphon and their effects. The following results are observed.

1. Working fluid, filling ratio, tube material and dimensions, lengths (evaporator, condenser and adiabatic section), heat load, coolant flow rate and temperature, operating pressure affects the thermal performance of thermosyphon.
2. For the effective heat transfer, surface area of condenser section should be greater or equal to the surface area of evaporator section. This condition can be achieved by varying diameter or length of sections.
3. For lower temperature range, refrigerants show effective heat transfer performance. Considering the effect of global warming due to the refrigerants having high global worming potential (GWP), it is necessary to use and search new refrigerants having less GWP
4. Evacuation of thermosyphon tube is compulsory to eliminate the inferior effects of non condensable gases. So considering the boiling point of working fluid and effect of non condensable gases, inside pressure of tube should be kept at appropriate level.
5. Circulation of working fluid in the thermosyphon completes due to gravity effect, so thermosyphon can’t work in horizontal position and heat transfer performance is superior between the angles 50° to 90°

There are still some problems and challenges in the mechanism of heat transfer enhancement and it is obvious that more research is needed in future in order to identify a new technique to improve the heat transfer properties of two phase thermosyphon

Nomenclature

h_e = heat transfer coefficient for evaporator section (W/m^2.K)
h_c = heat transfer coefficient for condenser section (W/m^2.K)

k = thermal conductivity (W/mK)

Q = maximum heat transferred by thermosyphon at any angle (W)

Q_{90} = heat transferred by thermosyphon at 90° (W)

q = heat supplied to evaporator section (W/m^2)

AR= aspect ratio = L_e/d

FR = filling ratio

P_{sat} = saturated pressure (pa)

T_w = wall temperature (°C)

L_e = length of evaporator section (m)

d = diameter of of tube (m)

Re = reynold number

Pr = prandlt number

μ = dynamic viscosity (kg/ms)

ρ = density (kg/m^3)

σ = surface tension (N/m)

h_{fg}= latent heat of vapourisation (kJ/kg)

Bo = bond number = $d\,[\sigma g(\rho_l - \rho_v)/\rho_v^2]^{1/2}$

Ku = kutateladze number = $q/[h_{fg}\rho_v\{\sigma g(\rho_l - \rho_v)/\rho_v^2\}^{1/4}]$

Ku*= modified Kutateladze number = $Ku.(d/Le).(\rho_v/\rho_l)$

Subscripts

l = liquid

v = vapour

cw = cooling water

hw = hot water

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