Investigation on the Effect of Filling Ratio on the Steady State Heat Transfer Performance of A Vertical Two Phase Closed Thermosyphon

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Abstract— Filling ratio of the working fluid has a predominant effect on the heat transfer characteristics of a two-phase closed thermosyphon (TPCT). A comprehensive model is developed to investigate the effect of filling ratio on the steady-state heat transfer performance of a vertical TPCT. Three types of flow pattern and two types of transition, according to the distribution of liquid film and liquid pool, are considered in this model, while other models generally focus on only one or two types of them. The total heat transfer rate of liquid pool, including those of natural convection and nucleate boiling, is calculated by combination of their effective areas and heat transfer coefficients. New correlations of the effective area are proposed based on the experimental results from other study. Two different geometries of the TPCT with nitrogen as working fluid are performed experimentally, and the evaporator temperatures accord well with the theoretical calculation. And the calculated results are compared with those by other empirical heat transfer correlations for liquid pool. The range of filling ratio, which can keep a TPCT steady and effective, is proposed based on analysis and comparison. The effects of heat input, operating pressure and geometries of the TPCT on the range are also discussed.

Keywords: Two-Phase Closed Thermosyphon (TPCT)

I. Introduction

Every day, cooling requirement in electronic industries increases abruptly due to greater functionality, faster operation, reduction in size and weight, and cost reduction of electronic products. Combination of faster operation and reduction in size resulted in high volumetric heat generation in electronic components leading to failure in the electronic device. The study proposed in this paper presents experimental results about the heat and mass transfer performances of a small dimension CLTPT operating at atmospheric and sub-atmospheric conditions with the perspective of defining design criteria of systems based on this principle as solar collectors. The A thermosyphon is a two phase heat transfer device that transports heat from one point to another by phase change mechanism. In which the heat transfer takes place through evaporation and condensation processes, and the working fluid is re-circulated from the condenser to the evaporator by gravitational force. However, in some cases, the working fluid is re-circulated by capillary forces. Since the high performance weightless TPCTs are demanded in industries, many investigations have been performed by altering the design and working fluids.

II. Working Principles of Heat Pipe

The operation of a heat pipe is shown in Figure 1.1the components of a heat pipe are a sealed container (pipe wall and end caps), a wick structure, and a small amount of working fluid which is equilibrium with its own vapor.

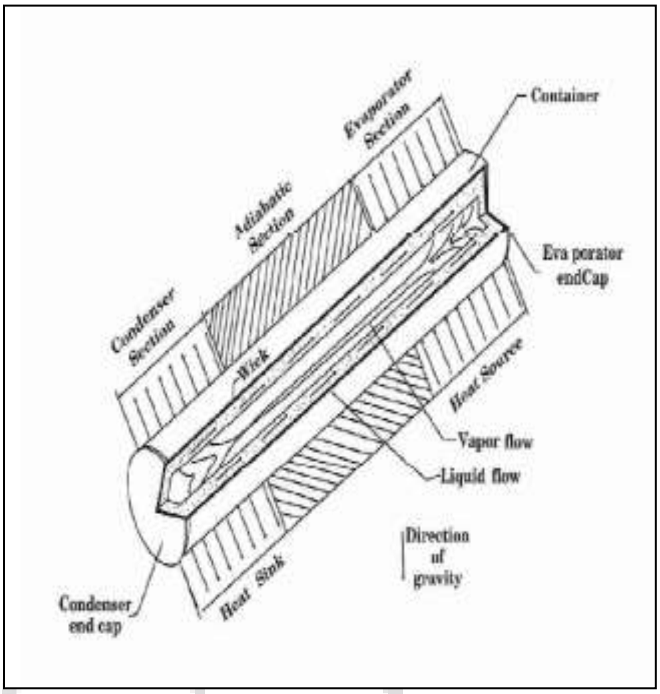

Fig. 1.1: Schematic of a conventional heat pipe showing the principle of operation and circulation of the working fluid

The length of the heat pipe is divided into three parts: evaporator section, adiabatic (transport) section and condenser section. A heat pipe may have multiple heat sources or sinks with or without adiabatic sections depending on specific applications and design. Heat is applied to the evaporator section by an external source and it is conducted through the pipe wall and wick structure, where the working fluid vaporizes, The resulting vapor pressure drives the vapor through the adiabatic section to the condenser, where the vapor condenses, releasing its latent heat to the provided heat sink.

The condensed fluid is pumped back to the evaporator section by capillary pressure created in the wick pumps. So that, the latent heat of vaporization transport continuously from the evaporator section to thecondenser section. This process will be prolonged as long as enough capillary pressure is there to pump the condensate back to the evaporator.

III. Literature review

A. General

The research performed so far on thermosyphon shows the thermal effectiveness inwaste heat recovery system and many other heating and cooling applications. A good deal of work is continuing in enhancing the heat transfer rate by changing the filling ratios and the working fluids used in thermosyphon. The literature revealed that the heat transfer characteristics of the types of heat pipe depends on the following parameters

1) Filling Ratio
2) Operating Temperature
3) Working Fluids
4) Input Power
5) Geometric Dimensions (Diameter, Orientation)

B. Thermal Performance of Two Phase Thermosyphon

Brusly Solomon et al. (2015) studied Heat transfer characteristics of an anodized two-phase closed thermosyphon (TPCT) with refrigerant as the working fluid is studied and compared with that of a non-anodized one. A simple anodization is performed to make a porous structure on the inner wall of TPCT. The anodized and non-anodized TPCTs charged with a blend of R600a and R290 are tested for the heat input range of 50–200 W. The effects of filling ratio, inclination angle, heat input and anodized surface on the performance of the TPCTs are investigated. Due to the anodization, the evaporator heat transfer coefficient enhances up to 33% at the inclination angle of 45_ for the heat input of 200 W. Also, total thermal resistance of the anodized TPCT is reduced by 17%, 20% and 23% respectively for horizontal, inclined and vertical positions when compared to the non-anodized TPCT. Enhancements in the surface area, number of nucleation sites, increased bubble frequency, intensified bubble interaction and thin film evaporation are major factors for the performance enhancement in the anodized TPCT.

R. Renjith Singh et al. (2015) presents the thermal performance of a flat thermosyphon with and without anodized innersurface. Anodization is performed to prepare a uniform coating on the inner side of the thermosyphon.Both non-anodized and anodized thermosyphons charged with acetone and tested in the heat inputrange of 50–300 W. Experiments are conducted for anodized and non-anodized flat thermosyphon setvarious inclination angles (0, 45, 90o) and fill ratios (40%, 60% and 100%). It is found that fill ratioand inclination angle has a significant effect on the performance of the thermosyphon. The total thermalresistance of the anodized thermosyphon is reduced by 20% when compared to the non-anodizedthermosyphon. The pore density of the anodized surface has increased almost 90% than the pore densityof non-anodized surface. Both evaporator and condenser heat transfer coefficient of anodized thermosyphonis enhanced, when compared to that of non-anodized thermosyphon. The maximum enhancementin heat transfer coefficients of the evaporator and condenser in the anodized thermosyphon is 9%and 27% respectively, when compared to non-anodized thermosyphon at a heat flux of 49 kW/m2. Theperformances of flat and cylindrical anodized thermosyphons are compared and it is found that the flatthermosyphon performed better than the cylindrical one. The heat transfer coefficient in evaporator andcondenser of flat thermosyphon is enhanced to 69% and 56% respectively when compared to thecylindrical one at a heat flux of 50 kW/m2.

Ali Chehade et al. (2015)present an analytical model for a thermosyphon loop developed for cooling air inside the communication cabinet. The proposed model is based on the combination of thermal and hydraulicmanagement of two-phase flow in the loop. Experimental tests on a closed thermosyphon loop areconducted with different working fluids that could be used for electronic cooling. Correlations force condensation and evaporation heat transfer in the thermosyphon loop are proposed. They are used in themodel to calculate condenser and evaporator thermal resistances in order to predict the cabinet operatingtemperature, the loop's mass flow rate and pressure drops. Furthermore, various figures of meritproposed in the previous works are evaluated in order to be used for selection of the best loop's workingfluid. The comparative studies show that the present model well predicts the experimental data. Themean deviation between the predictions of the theoretical model with the measurements for operatingtemperature is about 6%. Besides, the model is used to define an optimal liquid and vapor lines diametersand the effect of the ambient temperature on the fluid's mass flow rate and pressure drop.

Zhen Tong et al. (2015) studied environmentally friendly natural fluid with excellent thermodynamic and transport properties,carbon dioxide is an effective alternative refrigerant. This study presents an experimental investigation ofan R-744 based two-phase thermosyphon loop(LTS) used to cool a data center. With a heat transfer ratechange of 1e4 kW, the thermal resistance and driving temperature difference of the LTS are examined.The total thermal resistance decreases with increasing heat transfer rate due to the reinforced flowboiling heat transfer of R-744. The R-744 LTS can work under a small driving temperature difference of5 0C. According to a contrast experiment, the R-744 LTS has superior heat transfer performance, with adriving temperature difference that is 2 0C smaller than that of an R-22 LTS when the heat transfer rate is2 kW. Besides, a theoretical model is also used to analyze the performance of the LTS. The calculatedresults show that the air-side thermal resistance accounts for the majority (68e82%) of the total thermalresistance.

M.M. Sarafraz et all, (2015) This paper focuses on fouling formation of Nanofluid in a gravity-assisted thermosyphon equipped with a mesh screen wick. A transient study has been established on the fouling resistance of water-based TiO2Nanofluids at different operating conditions comprising the applied heat flux, mass concentration and inclination of thermosyphon. Nanofluids were prepared using prolonged sonication, stirring, and pH control. Triton X-100 was utilized as a dispersant. The thermosyphon is a copper made tube, which is dimensionally 10.7 mm and 12 mm for inner and outer pipe diameters respectively and total length of 280 mm. Transient results over the extended time reveal a considerable deterioration of heat transfer coefficient and thermal performance as a result of fouling formation inside the wick at evaporator section. According to the results, rate of fouling can be enhanced by increasing the Nanofluid mass concentration. Intensification of fouling on wick structure and internal wall of evaporator causes instabilities in thermal performance of thermosyphon over the time, which eventually causes the thermosyphon failure. This point has been ignored by most of previous researchers, which has a considerably negative impact on thermal performance of thermosyphon at longer operating time and higher heat loads. Therefore, a new fouling resistance model has been re-developed combining the microfluidic typical models. This model can predict the fouling resistance of Nanofluid inside the thermosyphon with approximate deviation of 30%.

Jiang He et al. (2014) studied non-condensable gas (NCG) generated inside two-phase heat transfer devices can adversely affect thethermal performance and limit the lifetime of such devices, extensive experimentinvestigation of the effect of NCG on the steady-state operation of an ammonia-stainless steel loopthermosyphon was conducted. In the experiments, nitrogen was injected into the loop thermosyphonasNCG, and the thermal performance of the loop thermosyphonwas tested at different NCG inventories,heat loads applied to the evaporator and condenser cooling conditions, i.e. natural air cooling or circulatingethanol cooling. Experimental results reveal that NCG elevates the steady-state operating temperatureof the evaporator, especially when the loop thermosyphon is operating in the low temperaturerange; meanwhile, the more NCG exists in the loop thermosyphon, the higher the operating temperatureof the evaporator, and the lower the reservoir temperature. In addition, the existence of NCG results inthe decrease of the overall thermal conductance of the loop thermosyphon, and the overall thermalconductance under the ethanol cooling condition may be even lower than that under the air coolingcondition when the heat load is smaller than a certain value. Finally, the experimental results areanalyzed and explained.

Alessandro Franco et al. (2013) designed and realized an experimental test rig for the analysis of Closed Loop TwoPhaseThermosyphons (CLTPT) of small dimensions where heat flow rate up to 1.7 kW can be furnished.The experimental test rig consists of an evaporator and a water cooled horizontal condenser placed about1 m over the evaporator. The main characteristic of this apparatus is the presence of three different waysof measuring the mass flow rate: a continuous mode, an integral mode and an indirect mode.The purpose of this analysis is to investigate the correlation between mass flow rate and heat flow rate.The results of an experimental analysis by using water and ethanol as tested fluids at different operatingconditions are shown discussed and analyzed.The influence of several parameters on the performances was studied experimentally: in particularheat load, operating pressure and fluid filling. The limits in the heat and mass transport are evidencedtogether with the unstable behavior at the high heat input.Fromhis work, understanding and useful information are provided for designing and building a twophasethermosyphon for systems like solar heating.

Bandar Fadhlet al. (2013) worked for heat pipe technology for heat recovery and energy saving in a vast range of engineeringapplications has been on the rise in recent years. Heat pipes are playing a more important role in manyindustrial applications, particularly in improving the thermal performance of heat exchangers andincreasing energy savings in applications with commercial use. a comprehensive CFDmodeling was built to simulate the details of the two-phase flow and heat transfer phenomena during theoperation of a wickless heat pipe or thermosyphon, that otherwise could not be visualized by empirical or experimental work. Water was used as the working fluid. The volume of the fluid (VOF) model in ANSYSFLUENT was used for the simulation. The evaporation, condensation and phase change processes in athermosyphonwere dealt with by adding a user-defined function (UDF) to the FLUENT code. The simulationresults were compared with experimental measurements at the same condition. The simulation was successfulin reproducing the heat and mass transfer processes in a thermosyphon. Good agreement wasobserved between CFD predicted temperature profiles and experimental temperature data.

A. Kamyaret all, (2013) His study based onPerformance of thermosyphons could be improved by various methods like changing the transport properties and heat transfer characteristics of the working fluid. Nano fluid, referring to a colloidal suspension of a base fluid and Nano sized (1– 100 nm) solid particles, is an option to achieve this target. Combining the heat exchange nature of thermosyphons and distinct thermal characteristics of Nano fluids can open up new horizons in the field of heat transfer. His study concentrates on the thermal performance of a two-phase closed thermosyphon filled with two nanofluids using water as the base fluid mixed with Al2O3 and TiSiO4 nanoparticles. Nanofluids were prepared in different volumetric concentrations (0.01%, 0.02%, 0.05% and 0.075%). Different heat loads (40 W, 70 W, 120 W, 180W and 210 W) were applied to the evaporator section. Results demonstrate that both nanofluids improve the performance through reduction in thermal resistance by 65% (at 0.05 vol.% for Al2O3) and 57% (at 0.075 vol.% for TiSiO4). Other improvements were also found in forms of increase in heat transfer coefficient and decrease in evaporator wall temperature.

Matthias H. Buschmannet all, (2013) Confronted with limited energy and material resources and undesirable manmade climate changes, science is searching for new and innovative strategies to save, transfer and store thermal energy. Currently, one of the most intensively discussed options are the so-called nanofluids. Nanofluids are suspensions consisting of a liquid base fluid and solid particles of sizes ranging from 10 nm to 200 nm. The higher thermal conductivity of these nanoparticles leads to an increased effective thermal conductivity of the fluid which, the general expectation is, should enhance the heat transfer of the device. This overview aims to compile results of the application of nanofluids in thermosyphons, heat pipes, and oscillating heat pipes. The general goal is to draw conclusions with respect to the potentials for improvement of the thermal performance of these gadgets. Additionally, possible mechanisms which may generate these improvements are discussed. All together 38 experimental studies and 4 modeling approaches are analyzed. While most investigations recognize nanofluids as an advantageous working fluid, some others report negative effects.

Performance effects which are related to filling ratio, inclination angle, and operation temperature seem to be similar to those for classical working fluids. Several authors report a decrease of the thermal resistance or an increase of the efficiency with increasing concentration, but also a reversing of this trend if a certain optimal concentration is exceeded. This observation mainly follows with a significant increase of the evaporator heat transfer coefficient. The condenser heat transfer coefficient seems to be not or only weakly affected. Base fluid, nanoparticle material, size and shape, and the stabilization of the suspension have an influence on the thermal performance. However, the limited number of experiments does not allow drawing firm conclusions. The main mechanism responsible for the improved thermal performance seems to be a porous layer built from nanoparticles on the evaporator surface. Additional positive effects may follow from the changed thermophysical properties of the working fluid.

Janusz T. et al. (2012) designed two-phase thermosyphon heat exchanger is proposed. This designfeatures an evaporator tube bundle consisting of smooth, corrugated or porous coated tubes. The prototype heat exchanger consists of two horizontal cylindrical vessels connected by two risers and a down comer. Tube bundles placed in the lower and upper cylinder function as an evaporator anda condenser. The operation of a two-phase thermosyphon is determined primarily by the evaporator's performance. Therefore, an experimental investigation was conducted to determine the effects of the evaporator tube pitch (1.7d and 2.0d), the liquid head and fluid type on heat transfer in this two-phase thermosyphon heat exchanger. The investigation concerned six prototype heat exchangers operating ina heat flux range of 5e70 kW/m2. As working fluids, distilled water, methanol and refrigerant R-141bwere utilized. The tested two-phase thermosyphon heat exchanger operates in a vacuum, and thereforethe working liquids boiled in temperatures ranging from 24 0C to 62 0C The obtained results indicate thatthe two-phase thermosyphon heat exchanger performs more effectively with an evaporator bundle comprising of porous coated tubes than with corrugated or smooth tubes. The evaporation heat transfer coefficient is strongly dependent on the liquid level above the top tube row (5 mm, 15 mm and 20 mm).

Robert W et al. (2012) studied two-phase thermosyphons. Two-phase thermosyphons are devices offering very high thermal conductance. The study reported he re-examined two-phase thermosyphons of length 2200 mm and external diameter 15.9 mm. Potential applications include air to air heat. The work is 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 showed a watere5% ethylene glycol mixture was a suitable replacement fluid, although under certain conditions its performance was less than that of R134a. The tests also showed water alone can give the highest heat transfer, although it is not suited to the targettemperaturerange, and methanol did not perform as well as R134a for most of the experimental range.A predictive model based on the equations published by ESDU International was developed. It was found to give good results for water, workable results for watere5% ethylene glycol, be of limited use form ethanol and be unsuitable for R134a.

VadimTsoiet al. (2011) examines the thermal performance of a newly devised plate-type two-phaseloopthermosyphon with cooling applications to electronic boards of telecommunication systems. Theevaporation section is configured as the inter-connected multi channels to emulate the bridging boilingmechanism in pulsating thermosyphon. Two thermosyphon plates using water as the coolant with fillingratios (FR) of 0.22 and 0.32 are tested at sub-atmospheric pressures. The vaporeliquid flow images aswell as the thermal resistances and effective spreading thermal conductivities are individually measuredfor each thermosyphon test plate at various heating powers. The high-speed digital images of the vaporeliquid flow structures reveal the characteristic boiling phenomena and the vapor liquid circulation inthe vertical thermosyphon plate, which assist to explore the thermal physics for this type of loopthermosyphon. The bubble agglomeration and pumping action in the inter-connected boiling channelstake place at metastable non-equilibrium conditions, leading to the intermittent slug flowswitha pulsation character. Such hybrid loop-pulsating thermosyphon permits the vaporeliquid circulation inthe horizontal plate. Thermal resistances and spreading thermal conductivities detected from the presentthermosyphon plates; the vapor chamber flat plate heat pipe and the copper plate at free and forcedconvective cooling conditions with both vertical and horizontal orientations are cross-examined. In mosttelecommunication systems and units, the electrical boards are vertical so that the thermal performancedata on the vertical thermosyphon are most relevant to this particular application.

Gabriela Huminicet all, (2011) The heat transfer characteristics of the heat transfer devices can be done by changing the fluid transport properties and flow features of working fluids. In his study, therefore, the heat transfer characteristics of two-phase closed thermosyphon (TPCT) with iron oxide-nanofluids are presented. The TPCT is fabricated from the copper tube with the outer diameter and length of 15, 2000 mm, respectively. The TPCT with the de-ionic water and nanofluids (water and nanoparticles) are tested. The iron oxide nanoparticles with mean diameter of 4–5 nm were obtained by the laser pyrolysis technique and the mixtures of water and nanoparticles are prepared using an ultrasonic homogenizer. Effects of TPCT inclination angle, operating temperature and nanoparticles concentration levels on the heat transfer characteristics of TPCT are considered. The nanoparticles have a significant effect on the enhancement of heat transfer characteristics of TPCT. The heat transfer characteristics of TPCT with the nanofluids are compared with that the based fluid.

Jouhara and Robinson (2010) investigated a small diameter and compact thermo syphon with four different working fluids: water, FC-84, FC-77 and FC-3283. The copper thermosyphon was 200 mm long with an inner diameter of 6 mm, the evaporator length was 40 mm and the condenser length was 60 mm. The thermal performance of the water-charged thermosyphon also outperformed the other three working fluids in both the effective thermal resistance as well as maximum heat transport capabilities. Even so, FC-84, the lowest saturation temperature fluid tested, shows marginal improvement in the heat transfer at low operating temperatures.

MasoudRahimiet al. (2010) His study on the effect of the condenser and evaporator resurfacing on overall performance of a 1 m height closed two-phase thermosyphon. Water was used as working fluid with a fill ratio and operating pressure was 0.75 and 160 mbar, respectively. The thermosyphon performances for plain and modified thermosyphon were studied at 44 power inputs from 43W to

668 W. The results show that by making the evaporator more hydrophilic and the condenser more hydrophobic, it will be possible to increase the average thermal performance by15.27% and decrease the thermal resistance by 2.35 times compared with the plain one.

T. Parametthanuwatet all, (2010) The effect of using silver nanofluid (de ionized water mixed with silver Nano and particles less than 100 nm) on the thermal characteristics of a two-phase closed thermosyphon in an operating state was investigated in this research. The thermosyphon was made with copper tubes with 7.5, 11.1 and 25.4 mm ID. The filling ratios of 30%, 50% and 80% by evaporator length and aspect ratios of 5, 10, and 20 with an inclination angle 900. The operating temperatures were 400C, 500C and 600C. The research reports the effect of dimensionless parameters on heat-transfer characteristics were: Le di, Bo, Pr, We, Fr, Ja, Co, Nu, Ar, Gr and Ku. It was found that the filling ratio has no effect on the ratio of heat-transfer characteristics in the vertical position, but the properties of the working fluid affected the heat-transfer rate. In addition a correlation for predicting the heat flux for the two-phase closed thermosyphon in the vertical position has been established.

PiyushSabharwall et al. (2009) studied hydrogen production processes, both powered by Next Generation Nuclear Plant (NGNP), investigation at the Idaho National Laboratory and University of Idaho. The first is high temperature steam electrolysis utilizing both heat and electricity, and the second is thermo-chemical production through the sulfur iodine process which primarily utilizes heat. Both processes require high temperature (>850◦C) for enhanced efficiency; temperatures indicative of NGNP. Safety and licensing mandates prudently dictate that the NGNP and the hydrogen production facility be physically isolated, perhaps requiring separation of over 100m. There are several options to transferring multi-megawatt thermal power over such a distance. One of the options is two-phase heat transfer utilizing a high temperature thermosyphon. Heat transport occurs via evaporation and condensation, and the heat transport fluid is re-circulated by gravitational force. A thermosyphon has the capability to transport heat at high rates over appreciable distances, virtually isothermally and without any requirement for external pumping devices. His paper addresses the engineering design elements of an industrial-scale (50MW), high temperature controllable thermosyphon for NGNP process heat transfer. Although several different working fluids are under consideration, alkali metals are used here in as reference fluids to illustrate elements of design.

S.H. Noie, et all, (2009) His study consist of two-phase closed thermosyphon (TPCT) is a device for heat transmission. It consists of an evacuated close tube filled with a certain amount of working fluid. Fluids with nanoparticles (particles smaller than 100 nm) suspended in them are called nanofluids that they have a great potential in heat transfer enhancement. In the study, we combined two mentioned techniques for heat transfer enhancement. Nanofluids of aqueous Al2O3 nanoparticles suspensions were prepared in various volume concentration of 1–3% and used in a TPCT as working media. Experimental results showed that for different input powers, the efficiency of the TPCT increases up to 14.7% when Al2O3 / water nanofluid was used instead of pure water.

Ming Zhang, et al.(2008) electronics cooling has become a key factor for improving the performance of electronic devices. An effective thermal spreader can achieve a more uniform heat flux distribution and thus increase heat dissipation in heat sinks. Two-phase thermosyphon is highly effective thermal spreader.

In order to observe boiling and condensation phenomena, a transparent two-phase thermosyphon was prepared for observation and study. The characteristics of phase change heat transfer were experimentally investigated. The performance of the two-phase thermosyphon with different working fluids was measured for different heat fluxes. The experimental results show that it has the ability to level temperature and produces a very uniform temperature distribution in the condensation surface. The impairment of cooling condition on the external side of the condensation plate worsens the performance of the two-phase thermosyphon. Throughout the tested heat flux range in our experiment, the two-phase thermosyphon with water as working fluid has a better performance than that with ethanol as working fluid.We also studied the ability of the grooved evaporation surface to increase boiling heat transfer. Our experiments prove that the two-phase thermosyphon with a grooved evaporation surface has a much better performance due to the increased heat transfer at the evaporation surface. By comparing the thermal resistance of a solid copper plate to that of the two-phase thermosyphon, it is suggested that the critical heat flux condition should be maintained if two-phase thermosyphon is to be used as efficient thermal spreaders for electronics cooling.

B. Jiao, L.M. Qiuet al. (2008)Filling ratio of the working fluid has a predominant effect on the heat transfer characteristics of a two-phase closed thermosyphon(TPCT). A comprehensive model is developed to investigate the effect of filling ratio on the steady-state heat transfer performance ofa vertical TPCT. Three types of flow pattern and two types of transition, according to the distribution of liquid film and liquid pool,are considered in this model, while other models generally focus on only one or two types of them. The total heat transfer rate of liquidpool, including those of natural convection and nucleate boiling, is calculated by combination of their effective areas and heat transfercoefficients. New correlations of the effective area are proposed based on the experimental results from other study. Two different geometriesof the TPCT with nitrogen as working fluid are performed experimentally, and the evaporator temperatures accord well with thetheoretical calculation. And the calculated results are compared with those by other empirical heat transfer correlations for liquid pool.The range of filling ratio, which can keep a TPCT steady and effective, is proposed based on analysis and comparison. The effects of heatinput, operating pressure and geometries of the TPCT on the range are also discussed.

Sameer Khandekaret all, (2008) Nanofluids, stabilized suspensions of nanoparticles typically <100 nm in conventional fluids, are evolving as potential enhanced heat transfer fluids due to their improved thermal conductivity, increase in single phase heat transfer coefficient and significant increase in critical boiling heat flux. In this paper, he investigate the overall thermal resistance of closed two-phase thermosyphon using pure water and various water based nanofluids (of Al2O3, CuO and laponite clay) as working fluids. We observe that all these nanofluids show inferior thermal performance than pure water. Furthermore, we observe 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. A scaling analysis is presented which shows that the increase in wettability and entrapment of nanoparticles in the grooves of the surface roughness cause decrease in evaporator side Peclet number that finally leads to poor thermal performance.

S.H. Noieet al. (2006) Hi studied experimentally and theoretically to investigate the thermal performance of an air-to-air thermosyphon heat exchanger. Many factors affect the thermal performance of thermosyphon heat exchangers including velocity and temperature of input air, type and filling ratio of the working fluid, and pipe material. The air-to-air thermosyphon heat exchanger has been designed, constructed and tested in a test rig under steady state conditions. The lengths of both the evaporator and condenser sections of the heat exchanger were 600 mm and its central adiabatic section had a length of 100 mm. The heat exchanger had 90 plate finned copper thermosyphons arranged in 6 rows. A test rig was constructed and developed wherein the heated air is recycled into the evaporator section of thermosyphon heat exchanger. The temperature across the evaporator section was varied in the range of 100–250 0C while the inlet temperature to condenser section was nearly constant 25 0C. Distilled water was used as the working fluid with a fill ratio of 60% of the evaporator section length. The air face velocity ranged from 0.5 to 5.5 m/s and the heat input into the evaporator section was varied between 18 and 72 kW using electric heating elements. A computer simulation program based on the effectiveness-NTU method was developed to estimate the outlet temperature by iteration as well as thermal performance of the thermosyphon heat exchanger. Also several experiments were carried out under different operating conditions by varying the parameters in order to determine and investigate their effect on the thermal performance of the thermosyphon heat exchanger. The overall effectiveness of the thermosyphon heat exchanger obtained from experiments varied between 37% and 65%.

Kim et al. (2003) developed a mathematical model for heat and mass transfer in a miniature heat pipe with a grooved wick and solved analytically to yield the maximum heat transport rate and the overall thermal resistance under steady-state conditions. The effects of the liquid-vapor interfacial shear stress, the contact angle, and the amount of initial liquid charge have been considered. In order to verify the model, experiments for measuring the maximum heat transport rate and the overall thermal resistance are conducted. The analytical results for the maximum heat transport rate and the total thermal resistance based on the proposed model are shown to be in close agreement with the experimental results. From the proposed model, numerical optimization is performed to enhance the thermal performance of the miniature heat pipe. It is estimated that the maximum heat transport rate of outer diameter 3 and 4 mm heat pipes can be enhanced up to 48% and 73% respectively, when the groove wick structure is optimized from the existing configurations. Similarly, the total thermal resistance of these heat pipes can be reduced by 7% and 11 % respectively, as a result of optimization.

Lin et al. (2002) developed High performance miniature heat pipes for the cooling of high heat flux electronics using new capillary structures made of a folded copper sheet fin. Using the folded sheet fin, capillary flow channels with fully and partially opened grooves are made by electric¬discharge-machining technique. Heat pipes with two different capillary structures and different fill amounts are tested in the horizontal orientation. Three heating modes of the evaporator are simulated by activating different numbers of chip resistors. The heat pipe with partially opened groove wick performs better than that with fully opened groove wick. The condenser heat transfer coefficient is higher by 120% or greater in the case of the former wick type compared to the latter at an operating, temperature of 1l0°C.The ratio of the heat rate through the top side cooler to that through the bottom side cooler of the condenser decreases with an increase of the input power. It has been indicated that the heat transfer coefficients of the evaporator and condenser are still greater for heat pipe with partially opened capillary fins than for heat pipe with fully opened capillary fins at the high heat fluxes.

Wang and Vafai (2000) investigated the thermal performance of a flat-plate heat pipe during startup and shut down operations. The results indicate that the wick in the evaporator section provides the largest resistance to the heat transfer process followed by the wick in the condenser section. It is found that the heat transfer coefficient has an insignificant effect on the maximum temperature difference across the heat pipe where this difference refers to the maximum difference on the outside surfaces of the flat-plate heat pipe. It is found that the temperature difference across the heat pipe depends mainly on the input power. Empirical correlations for the maximum temperature rise as a function of input heat flux and heat transfer coefficient, and the maximum temperature difference as a function of input heat flux were determined. Correlations were also given for the time constants in terms of heat transfer coefficients.

Yarinet al. (2002) studied the thermo hydrodynamic characteristics of a two-phase capillary flow with phase change at the meniscus. A dimensional model is proposed for such a flow. It takes into account the principal characteristics of the phenomenon, namely, the effects of the inertia, pressure, gravity, friction forces and capillary pressure due to the curvature of the interface surface, as well as the thermal and dynamical interactions of the liquid and vapor phases. An equation for stationary two-phase flow regimes in heated microchannel is derived. This equation is applied to classify the operating parameters, corresponding to various types of flow. The rate of vaporization (the liquid's velocity), the liquid and vapor temperatures, the position of the meniscus in the microchannel, its hydraulic resistance and the thermal losses are determined by eight non-dimensional groups, accounting for the effects of heat transfer, phase change, as well as inertia, friction, surface tension and gravity forces. The numbers of such non-dimensional groups are reduced to 4 by introducing a general parameter: the capillary height, which depends on the Weber, Froude and Euler numbers. A decrease in the gravity leads to the displacement of the meniscus toward the outlet and to a decrease in the heat losses and an increase in the liquid and vapor velocities. A decrease in the microchannel diameter leads to a monotonous increase in the liquid and vapor velocities, whereas the dependence of the meniscus position versus d has an extreme.

Zhanget al.(2001) investigated Forced convective condensation in miniature channels is capillary blocking that occurs due to condensation in a horizontal miniature tube and between parallel plates is simulated by using the Volume of Fluid (VOF) method. Saturation temperature, surface tension, and diameter on effective condensation length, film thickness, and heat transfer coefficient are investigated. The film thickness and the condensation length decrease as the hydraulic diameter or the distance between parallel plates decrease. When the total mass flow rate drops, the condensation length decreases significantly. When the surface tension increases, the liquid film thickness up to the blocking point decreases and also the condensation length decreases for both tubes and parallel plates.

Qu and Mudawar (2002) investigated the pressure drop and heat transfer characteristics of a single-phase micro-channel heat sink. The heat sink was fabricated from oxygen-free copper and fitted with a polycarbonate plastic cover plate. The heat sink consisted of an array of rectangular micro¬channels 231 /J m wide and 713 /J m deep. The three-dimensional heat transfer characteristics of the heat sink were analyzed numerically by solving the conjugate heat transfer problem involving simultaneous determination of the temperature field in both the solid and liquid regions. The local and average heat transfer characteristics of the heat sink are studied. Higher Reynolds numbers and beneficial at reducing both the water outlet temperature and the temperatures within the heat sink also at the expense of greater pressure drop. The heat flux and Nusselt number also vary around the channel periphery, approaching zero near the corners.

Gabriela Huminic et al (2011)This paper presents an experimental investigation regarding the use of solid nanoparticles added to water as a working fluid. Tests were made on a thermosyphon heat pipe. The experiment was performed in order to measure the temperature distribution and compare the heat transfer rate of the thermosyphon heat pipe with nanofluid and with DI-water. The iron oxide nanoparticles were obtained by the laser pyrolysis technique. The tested concentration level of nanoparticles is 0%, 2%, and 5.3%. Results show that the addition of 5.3% (by volume) of iron oxide nanoparticles in water presented improved thermal performance compared with the operation with DI-water.

HussamJouharaet al (2010)an experimental investigation of the performance of thermosyphons charged with water as well as the dielectric heat transfer liquids FC-84, FC-77 and FC-3283 has been carried out. The copper thermosyphon was 200 mm long with an inner diameter of 6 mm, which can be considered quite small compared with the vast majority of thermosyphons reported in the open literature. The evaporator length was 40 mm and the condenser length was 60 mm which corresponds with what might be expected in compact heat exchangers. With water as the working fluid two fluid loadings were investigated, that being 0.6 ml and 1.8 ml, corresponding to approximately half filled and overfilled evaporator section in order to ensure combined pool boiling and thin film evaporation/boiling and pool boiling only conditions, respectively. For the Fluorinert liquids, only the higher fill volume was tested as the aim was to investigate pool boiling opposed to thin film evaporation. Generally, the water-charged thermosyphon evaporator and condenser heat transfer characteristics compared well with available predictive correlations and theories. The thermal performance of the water-charged thermosyphon also outperformed the other three working fluids in both the effective thermal resistance as well as maximum heat transport capabilities. EvenSo, FC-84, the lowest saturation temperature fluid tested, shows marginal improvement in the heat transfer at low operating temperatures. All of the tested Fluorinert liquids offer the advantage of being dielectric fluids, which may be better suited for sensitive electronics cooling applications and were all found to provide adequate thermal performance up to approximately 30–50W after which liquid entrainment compromised their performance

P. Amatachayaet al (2010) This study investigated the effects of cross-sectional geometries, filling ratio and aspect ratio on thermal performance of thermosyphon at different rates of heat input. Two cross-sectional geometries of thermosyphon (circular and flat)were used. Each cross-sectional geometrywas chargedwith distilledwaterwith different filling ratios, aspect ratios and heat input. The results indicated that the FTPCT had a higher averagewall temperature in the evaporator section than that of the CTPCT. The maximum heat input had a significant influence on the heat fluxes for each filling ratio and evaporator length. Heat fluxes were increasedwith an increase of aspect ratio and heat input and decreased slightly at the maximum aspect ratios.

Qi Baojin et al (2009) Experimental investigations were carried out to study heat transfer characteristics of titanium (commercially pure titanium, TA2)/water two-phase closed thermosyphon (Ti/H2O TPCT). Experiments of copper/ water (Cu/H2O) TPCT with same dimension and manufacturing process had also been performed for contrast. Experimental results show that there are no remarkable differences of heat transfer coefficients in evaporator (he) between the two kinds of TPCTs, whereas surprisingly the experimental results of heat transfer coefficient in condenser (hc) of Ti/H2O TPCTs are about 2–3 times more than that of Cu/H2O TPCTs, moreover the Nusselt's theoretical correlation based on laminar filmwise condensation is not suitable for simulating the hc of Ti/H2O TPCTs. Experimental results and theoretical analysis of surface free energy difference between condensate and solid surface indicate that the mixed condensation mode withdropwise and filmwise condensation coexisting on titanium surface result in the higher hc for Ti/H2O TPCTs.

L. Benkheira et al (2007) In the framework of the cryogenic cooling system design of a large superconducting magnet under construction at CERN-Geneva, heat transfer in two-phase He I natural circulation loop has been investigated experimentally. The experiments were conducted on a 2 m thermosiphon loop with copper tube of 10 mm inner diameter uniformly heated over a length of 0.95 m. All data were obtained near atmospheric pressure. Evolution of the exit vapour quality and wall superheat as a function of heat flux are presented and analyzed.A comparison between the two-phase heat transfer coefficient hTP determined in our study and the most relevant correlations available in literature is made. Further, we predict hTP with a correlation based on the combining effects of forced convection and nucleate boiling by a power-type asymptotic model. Finally, we present the boiling crisis study and we propose a critical heat flux correlation as a function of channel height to diameter ratio (z/D) to model our experimental results.

H. Imura et al (1983)An experimental study was made of 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 and previously-published 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 is made.

El-Genk et al (1993) Hisexperiments were performed to investigate the transient response of a water heat pipe to step changes in input power at different cooling rates. The copper heat pipe employs a double-layered, 150 mesh copper screen wick and its evaporator section was uniformly heated while the condenser section was convectively cooled. The time constants of the vapor temperature and the effective power throughput, for both heat-up and cool-down transients were determined as functions of the electric power input and the water mass flow rate in the cooling jacket of the condenser section. Both the vapor and wall temperatures were measured at ten axial locations along the heat pipe

M. Groll,et al(1980) His r&d work carried out an attempt was made to obtain performance data to subsequently generate analysis and design tools for gravity-supported heat pipes (reflux heat pipes) and thermosyphons. With an extended experimental program the performance limitation of screen-wick heat pipes has been determined as a function of various heat pipe parameters. A correlation could be derived allowing predicting the maximum performance. Similar experiments have been carried out with thermosyphons having smooth or rough inner surfaces. However, no quantitative correlations of the experimental data have been generated so far. In addition, a detailed study on the liquid-vapor interaction has been carried out. This was accompanied by preliminary experiments with a high-performance thermosyphon. A large number (26) of combinations of working fluids (8) and structural materials (9), especially suitable for the temperature range from near-room temperature up to about 250°C, has been tested for compatibility. A set of heat pipes with 6 different structural materials employing water and freon 21 as working fluids has been subjected to long-term tests with cycling heat inputs

IV. CONCLUSIONS

The study proposed in this paper presents experimental results about the heat and mass transfer performances of a small dimension TPCT operating at atmospheric and sub-atmospheric conditions with the perspective of defining design criteria of systems based on this principle as solar collectors. The study proposed in this paper presents experimental results about the heat and mass transfer performances of a small dimension CLTPT operating at atmospheric and sub-atmospheric conditions with the perspective of defining design criteria of systems based on this principle as solar collectors. Performance effects which are related to filling ratio, inclination angle, and operation temperature seem to be similar to those for classical working fluids. Several authors report a decrease of the thermal resistance or an increase of the efficiency with increasing concentration, but also a reversing of this trend if a certain optimal concentration is exceeded. This observation mainly follows with a significant increase of the evaporator heat transfer coefficient. The condenser heat transfer coefficient seems to be not or only weakly affected. Base fluid, nanoparticle material, size and shape, and the stabilization of the suspension have an influence on the thermal performance. However, the limited number of experiments does not allow drawing firm conclusions.

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