ISSN 2395-1621

# Parametric study of thermosyphon heat pipe: Review

[1]Phule N. L., [#2]Dongarwar P. R.

[1]nandkishor.phule@rediffmail.com
[2] prdongarwar71@gmail.com

[#1]Ph. D. Student, SCOE, Pune, Savitribai Phule University, Pune India
[#2]CME, Pune, India

**ABSTRACT**

**The performance of heat transfer is one of the most important research areas in the area of thermal engineering. Due to high heat transfer effectiveness of thermosyphon heat pipe, it has has its own importance in the low and medium temperature heat transfer. Researchers observed that geometrical factors have significant influence on the performance of thermosyphon. Therefore the experimental and computational study of thermosyphon is essential to find out the factors affecting the performance of thermosyphon. In this review paper main focus is given to parameters like filling ratio, aspect ratio, heat load, mass flow rate, inclination angle,different conventional working fluids ,nano fluids and different fluid vibrating techniques which affects on the thermal performance of thermosyphon. Also the new heat transfer enhancement techniques like resurfacing, use of ultrasonic wave and CFD analysis are highlighted. From the literature it seems to be need of new efficient heat transfer combined heat transfer augmentation technique is essential and mathematical modelling of thermal performance of two phase thermosyphon.**

***Keywords:*****Thermosyphon heat pipe, factors affecting on TPCT, Mathematical modelling, surface modifications, active heat transfer augmentation technique**

ARTICLE INFO

**Article History :**

Received:2nd November 2015

Received in revised form:

4th November 2015

**Accepted : 5th November 2015**

## I. INTRODUCTION

Due to the human need for energy, a more efficient way of using it is a major challenge in the scientific community.The thermal performance of thermosyphon is one the most important part of these types of investigation in the field of heat transfer. Thermosyphons are enclosed, passive two phase heat transfer devices. They make use of the highly 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 to as thermal superconductors because they can transfer large amounts of heat over relatively large distances with small temperature differences 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.They are proven to be very effective, low cost and reliable heat transfer devices for applications in many thermal management and heat recovery systems. They are used in many applications including but not restricted to passive ground/road anti-freezing, baking ovens, heat exchangers in waste heat recovery applications, water heaters and solar energy systems and are showing some promise in high-performance electronics thermal management for situations.

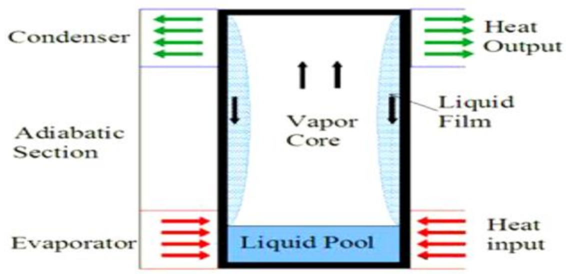


Fig.1.1- Two-phase closed thermosyphon working principle

 

A cross section of a closed two-phase thermosyphon is illustrated in fig.1.1 .The thermosyphon consists of an evacuated sealed tube that contains a small amount of liquid. The heat applied at the evaporator section is conducted across the pipe wall causing the liquid in the thermosyphon to boil in the liquid pool region and evaporate and/or boil in the film region. In this way the working fluid absorbs the applied heat load converting it to latent heat.

The vapour in the evaporator zone is at a higher pressure than in the condenser section causing the vapour to flow upward. In the cooler condenser region the vapour condenses thus releasing the latent heat that was absorbed in the evaporator section. The heat then conducts across the thin liquid film and exits the thermosyphon through the tube wall and into the external environment. Within the tube, the flow circuit is completed by the liquid being forced by gravity back to the evaporator section in the form of a thin liquid film. As the thermosyphon relies on gravity to pump the liquid back to the evaporator section, it cannot operate at inclinations close to the horizontal position.

Normally the heat transfer efficiency of a thermosyphon depends on the temperature of the heating source. In case, where the heat source has low temperature, it is found that the heat transfer process is insufficient because of difficulties in boiling of the working fluid at low temperature which leads to low efficiency of thermosyphon.

There are two approaches to overcome this problem as:-

- Using Mechanical Modification (i.e. active or passive heat transfer enhancement technique.)
- Using efficient working fluid.

First approach uses different active techniques for vibrating the working fluid in order to actuate the working fluid inside the thermosyphon heat pipe to be turbulent, with subsequent on heat transfer because passive techniques do not give superior result. There are many active techniques to vibrate the fluid such as surface vibration, fluid vibration, electrostatic fields etc . But from literature reviewed, some researchers concluded that ultrasonic vibration is one of most efficient technique for enhancement boiling .

Second approach is by using efficient working fluid. Many researchers have proposed that nano-fluids act as smart fluids and have high potential as working fluid in thermosyphon. The characteristics like positive gradient of thermal conductivity–temperature, high convective and boiling heat transfer coefficients compared to conventional working fluids makes them a suitable alternative for thermosyphon applications. On the contrary, the use of nanofluids poses some possible problems such as agglomeration of nano-particles, adverse effect of surfactant for stable suspension of nano particles in nano-fluid, interaction between boiling surface and nano fluids etc. Therefore, it is essential to minimize these problems so as to enable the effective use of nano-fluid heat transfer applications.

It is necessary to enhance performance and heat transfer characteristic of thermosyphon used for low/medium temperature applications. It is also necessary to propose the research work at low /medium temperature applications such as waste heat recovery equipments like air preheater, water heater and there is scope to upgrade the performance of solar energy extracting equipments like solar collectors used for solar water heating & air heating systems.

Also it is crucial to analyze thermal performance of thermosyphon heat pipe using nano -fluid under the influence of ultrasonic waves, to ensure the possibility of enhancement of heat transfer at low/medium temperature applications.

## II.EXTENSIVE LITERATURE SURVEY

A considerable experimental and theoretical research work has been carried out for different applications, with various design modification for improving thermosyphon performance. The literature related to this topic reveal that numerous works have been carried out in the field of high temperature applications, but there is lack of sufficient data on the actual performance of thermosyphon for low temperature applications. It is necessary to promote the performance of thermosyphon used for low temperature applications.

The literature pertaining to this research work reveal performance analysis of thermosyphon heat pipe by studying various prominent parameters of thermosyphon such as aspect ratio, filling ratio, temperature of heat source and sink, angle of inclination etc, for different conventional working fluids such as water, ethylene glycol,R11, R22 etc. Also different nano-fluids have been used as working fluids in thermosyphon and the performance has been analyzed. Some authors have studied boiling heat transfer phenomenon using conventional working fluids and nano-fluids under the effect of ultrasonic waves and proposed that ultrasonic vibration is one of most efficient technique to augment the heat transfer rate .

The literature related to previous research on thermosyphon heat pipe with both conventional(base) and nano-based fluids and use of ultrasonic waves in 'heat transfer enhancement' can be briefly summarized as below:-

M. Kannan and et al.[1], have experimentally investigated the performance of two phase closed thermosyphon. They found water has maximum heat transport capability as compared to other fluids such as ethanol, methanol and acetone in temperature range of 40$^{o}$C to70$^{o}$C and filling ratio range 30 to 90%.

S.H. Noie [2] ,had investigated effect of three input parameters such as heat transfer rates (100 < Q_ < 900W), the working fluid filling ratios (30 to 90%), and the evaporator lengths (aspect ratios) experimentally. The aspect ratios for these experiments were 7.45, 9.8, and 11.8. A smooth copper tube of total length of 980 mm with inside and outside diameters of 25 and 32 mm was employed with distilled water as working fluid. The effects of the aspect ratio and filling ratio on the heat transfer characteristics of a closed two-phase thermosyphon under normal operating conditions was investigated. This paper concluded that, the temperature distribution along the thermosyphon wall in the evaporator section was almost isothermal. The measured temperature along the condenser showed lower values. This drop of temperature is expected because of the internal resistances due to boiling and condensation. Maximum heat transfer rates for each aspect ratio take place at different filling ratios. For aspect ratio of 11.8 maximum heat transfer rate occurs when filling ratio is 60%, while for aspect ratios of 7.45 and 9.8 the corresponding filling ratios for maximum rate of heat transfer are 90% and 30% respectively. The boiling heat transfer coefficients for aspect ratio of 9.8 and filling ratios 30%, 60% and 90% were found to be in reasonable agreement with empirical correlations.

S.H. Noie and et al. [3] , In this study, $Al_2O_3$ nano-fluid is used as a working fluid for heat transfer enhancement. Nanofluids of aqueous $Al_2O_3$ nano-particles 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 $Al_2O_3$/water nano-fluid was used instead of pure water. Temperature distributions on TPCT confirm these results too.

Patil Aniket D and et al. [4], In this review paper main focus is given to parameters like filling ratio, aspect ratio, heat load, mass flow rate and inclination angle, which affects the thermal performance of thermosyphon. Also the new heat transfer enhancement techniques like resurfacing, use of ultrasonic wave and CFD analysis are enlighten. This paper concludes that there is need for the innovation of new heat transfer enhancement techniques and development of mathematical model considering multiple factors so that experimental investigation can be minimized.

S.U.S. Choi [5], investigated that larger relative surface area of nano-particles, compared to those of conventional particles, should not only significantly improve heat transfer capabilities, but also should increase the stability of the suspensions.

Das and et al. [6] examined the effect of temperature on thermal conductivity enhancement for nanofluids containing $Al_2O_3$ (38.4 nm) or CuO (28.6 nm) through an experimental investigation using temperature oscillation method. They observed that 2 to 4 fold increase in thermal conductivity can take place over the temperature range of 21$^{o}$C to 52$^{o}$C.

Tsai and et al.[7] also employed aqueous solutions of various-sized gold nanoparticles.They found a large decrease of thermal resistance of the heat pipe with nanofluids as compared with de-ionized water.

Senthilkumar R.and et al [8], found that the thermal efficiency of copper nano-fluid is higher than the base fluid DI water and thermal resistance significant reduction in thermal resistance.

Paisarn Naphon and et al. [9], concluded that pipe with 0.10% nano particles volume concentration, the thermal efficiency is 10.60% higher than that with the based working fluid.

Sameer Khandekar and et al.[10] **,** investigated the thermal performance of closed two-phase thermosyphon using water and various water based nanofluids (of Al2O3, CuO and laponite clay) as a working fluid. They observed that all these nanofluids show inferior performance than pure water.

Gabriela Humnic and et al. [11] **,**performed an experiment to measure the temperature distribution and compare the heat transfer rate of thermosyphon with diluted nanofluid (with 0%, 2% and 5.3% concentration) in DI-water and DI-water. The thermosyphon was a copper tube with internal and external diameter of 13.6mm and 15 respectively. The overall of length of thermosyphon was 2000mm (evaporator length-850mm, condenser length-850mm, adiabatic section-300). They obtained the results that the addition of 5.3% (by volume) of iron oxide nanoparticles in water improved thermal performance of thermosyphon.

Saravanan M and et al. [12]**,**An experimental study is conducted to explore the heat transfer phenomenon m n of two phase closed thermosyphon using nanofluids. Latest investigations show better thermal behavior such as improved thermal conductivity and convection coefficients in comparison to pure fluid or fluid with larger size particles. Two Phase Closed Thermosyphon is fabricated from a straight copper tube with the outer diameter and length of 6,240 mm respectively.Results of 18 experiments were performed using the working fluids (DI + nano(Cuo) + n-butanol and Cuo nano particle in DI water), three orientations (0°, 45° and 90°) and three heat input rates are reported. 40 nm Cuo nano particles with a concentration of 60mg/lit were used. Orientation range of 45°and 50° in particular are optimum for nano fluid. 45° is found optimal for DI + nano + n-butanol. The effect of orientation on the thermal performance is found significant.

Mathieu Legay and et al.[13] ,have presented useful review on enhancement of heat transfer by ultrasonic. They concluded that well-known ultrasonically induced effects such as acoustic cavitations, acoustic streaming, fluid particle oscillations, fouling reduction, modification of bubble behavior in boiling etc. are responsible for heat transfer improvement .Local heat transfer coefficient was shown to be multiplied between 2 and 5 times in the presence of an ultrasonic field. Ultrasonic waves appear as an interesting way to improve processes productivity especially to overcome transfer limitations. For what concerns heat transfer, ultrasound can also be regarded as a possible technical solution for heat exchange enhancement. Hence, a lot of publications dealing with fundamental studies can be found in the literature. But most of these works are performed at the laboratory scale involving academic setups and usually using classical low frequency ultrasound. It is also very important to note here that it is very difficult to distinguish the influence of these effects since they often occur simultaneously

Kim H. T.and *et al*. [14] , used ultrasonic waves to promote the pool boiling of water, and they found that the boiling heat transfer coefficient was increased by approximately 8%.

Oh and *et al*.[15] , studied the effect of ultrasonic waves on heat transfer in changing phase process of working fluid. The experimental results revealed that ultrasonic vibration accelerates the melting process as much as 2.5 times compared to the rate of natural melting.

D.W. Zhou [16], concluded that with an acoustic field generated into the working fluid, heat transfer was enhanced by Cu nanoparticles, irrespectively of heat flux. The trend becomes more obvious with the increasing of fluid sub cooling, sound source intensity and nano-fluid concentration.

K.A. Park and A. E. Bergle [17], performed experiments wereperformed with horizontal cylinders exposed to an ultrasonic field under saturated or subcooled conditions. A degradation of low heat flux boiling occurred when the pool was saturated, but boiling was improved when the pool was subcooled. The vertical test-section location and pool depth were significant only for the latter. Burnout heat fluxes for saturated and subcooled conditions were slightly increased by an ultrasonic field.

K. S. Ong and W. L. Tong [18],had conducted experimental investigation to determine the effects of inclination and fill ratio on the performance of a water-filled two-phase closed thermosyphon at low evaporator temperatures below 65$^{o}$C. The evaporator section was heated by resistance band heaters. The condenser section consisted of a concentric pipe water-cooled jacket. Experiments were carried out with fill ratios between 0.25 and 1.0 and at angles of inclination between 30 – 90 degrees from the horizontal. Evaporator power input was varied from 304 – 830 W. In order to maintain uniform cooling at the condenser section, coolant water mass flow rate was kept as high as possible. The effects of evaporator power input, inclination and fill ratio were determined. The performance of the thermosyphon was found to be independent of fill ratio and inclination within the limits of the experimental investigation. The mean evaporating and condensing heat transfer coefficients and the relationship between thermosyphon heat transfer and operating temperature difference between evaporator and condenser were determined.

M. Karthikeyan and et al. [19], had investigated the thermal performance of an inclined two phase closed thermosyphon with different working fluid experimentally in this paper. Distilled water and an aqueous solution that has a positive gradient of surface tension with temperature are used as the working fluid. A copper thermosyphon with a length of 1000 mm long, an inner diameter of 17 mm and an outer diameter of 19 mm was employed. Each thermosyphon was charged with 60% of the working fluid and was tested with an evaporator length of 400 mm and condenser length of 450 mm. The thermosyphon was tested for various inclinations of 45$^{\circ}$, 60$^{\circ}$ and 90$^{\circ}$ to the horizontal. Flow rate of 0.08 kg/min, 0.1 kg/min and 0.12 kg/min and heat input of 40 W, 60 W and 80 W were taken as input parameters. The thermal performance of aqueous solution charged two phase closed thermosyphon was best performed than the distilled water in both heat transfer and temperature distribution.

Yoshihiro Iida , Kentarou Tsutsui and et al.[20], were carried out a series of experiments to make clear systematically the effects of ultrasonic waves on natural convection, nucleate boiling and film boiling heat transfer from a heated 0.2 mm diameter platinum wire to saturated water or ethyl alcohol. The effects on the maximum and minimum heat flux points were also examined. The test wire is set in liquid above a 20 mm x 40 mm vibrating surface of an ultrasonic transducer whose resonance frequency is 28 kHz and maximum power is 33.6 W. A distinctive augmentation effect on heat transfer is observed in both the natural convection and film boiling heat transfer regions. An increase of about 20% in the maximum heat flux is obtained in both liquids by applying ultrasonic waves. The minimum heat flux point is raised at higher values of both the degree of superheat and the heat flux. The profiles of sound pressure along the centerline of the ultrasonic field and those of the heat transfer coefficients in natural convection and in film boiling were measured and compared. Heat transfer coefficients attained under ultrasonic waves are shown to be depend largely on the distance from the vibrating surface to the test position. In general, the sound pressure profiles resemble a deformed sine wave and are roughly identical with those of the heat transfer coefficient as regards their wavelength and their maximum and minimum. It is considered that the sound pressure of ultrasonic waves may, directly or indirectly, have some connection with the mechanism of heat transfer augmentation.

J. H. Jeong and Y. C. Kwon[21], have been experimentally investigated the effects of ultrasonic vibration on critical heat flux (CHF) under natural convection condition. Flat bakelite plates coated with thin copper layer and distilled water are used as heated specimens and working fluid, respectively. Measurements of CHF on flat heated surface were made with and without ultrasonic vibration applied to working fluid. An inclination angle of the heated surface and water subcooling are varied as well. Examined water subcoolings are 5°C, 20°C, 40°C and the angles are 0°, 10°, 20°, 45°, 90°, 180°. The measurements show that ultrasonic wave applied to water enhances CHF and its extent is dependent upon inclination angle as well as water subcooling. The rate of increase in CHF increases with an increase in water subcooling while it decreases with an increase in inclination angle. Visual observation shows that the cause of CHF augmentation is closely related with the dynamic behaviour of bubble generation and departure in acoustic field.

Carlo Bartoli and Federica Baffigi [22],had conducted basic an experimental research aimed to investigate the influence on the heat transfer rate of the ultrasounds, in free convection and in presence of liquid. In fact the ultrasonic waves induce, thanks to vibrations, turbulence on the dynamic field, and so an increase of the convection coefficient.The heater was a circular cylinder, immersed in distilled water and warmed up by Joule effect. The effect was observed since 1960s:different authors had studied the cooling effect due to the ultrasonic waves at different heat transfer regimes, especially from a thin platinum wire to water. They had chosen to investigate the subcooled boiling regime, because this one is the best condition for the heat transfer enhancement, according to the scientific literature. We have carried out a wide experimental study, varying the different water subcooling degrees, the ultrasonic generator power, the ultrasound frequency and the placement of the heater inside the ultrasonic tank, in function of the range of the values of heat flux per unit surface needed dissipating. These values were supplied us by a possible practical application of the ultrasonic streaming: the cooling of 3D highly integrated electronic components. These packaging systems should have to provide all future devices, such as electronics, actuators, sensors and antenna. In fact, for these systems the thermal problem is a critical challenge, because they do not have to overtake critical temperature, after that they could damage irreversibly. Moreover, the traditional cooling systems used in electronic do not seem to be useful for them. On the contrary, the results obtained with ultrasounds, allow heat transfer coefficient enhancement of about 50% to be reached. The purpose is to find out the set of optimal conditions, in order to apply successively all the results to a real packaging system.

Ho-Young Kim ,Yi Gu Kim and et al.[23], had reported the relationship between the flow behaviour induced by ultrasonic vibration and the consequent heat transfer enhancement in natural convection and pool boiling regimes. A thin platinum wire works as both a heat source and a temperature sensor. A high speed video imaging system is employed to observe the behaviour of cavitation and thermal bubbles. Experimental results showd that the effects of ultrasonic vibration on flow behaviour are vastly different depending on the heat transfer regime and the amount of dissolved gas. In the natural convection and subcooled boiling regimes, behaviour of cavitation bubbles strongly affects the degree of heat transfer enhancement. In saturated boiling,no cavitation occurs thus the reduced thermal bubble size at departure and acoustic streaming are major factors enhancing heat transfer rate. The highest enhancement ratio is obtained in natural convection regime where the effect of ultrasonic vibration is manifested through violent motion of cavitation bubbles.

Sompon Wongtom and et al.[24], had investigated the effect of sound waves on thermal performance of thermosyphon containing R-123 as working fluid. The results of this experiment showed that a thermosyphon under sound wave could increase the heat transfer rate by about 67.65%, depending on the best case of a heat pipe at 15$^{o}$ incline, 70$^{o}$C of hot water at evaporating section, with 100 Hz and a filling ratio of 70% working fluid.

 

T.Theachana1 and et al.[25], investigated the effect of sound waves on the performance of thermosyphon containing water .They concluded that an ultrasonic waves can enhance the heat transfer rate of a thermosyphon for evaporator temperature upto 65°C, filling ratio between 50% to 100% &frequency of the wave as 8 kHz.

Dongsheng Wen and et al.[26], had carried out systematic experiments to formulate stable aqueous based nanofluids using electrostatic stabilization method containing **γ-** alumina nano-particles (primary particle size 10-50 nm), and investigate their heat transfer behavior under nucleate pool boiling conditions. The results showd that alumina nano-fluids can significantly enhance boiling heat transfer upto 40% for particle loading of 1.25 % by weight.

Ganesh Ranakot and et al. [27], found that lot of controversies in the results in case of performance of nano-fluid in heat transfer augmentation. Still this paper concludes that nanofluids thermal conductivity increases with increment in particle volume fraction and temperature. The chaotic movement of nano particles increases fluctuation and turbulence of the fluids, which increases the heat exchange process. The effects of nanofluids like clustering of nanoparticle, coagulation should be avoided.

H.Z. Abou-Ziyan, A. Helali, M. Fatouh and M.M. Abo El-Nasr [28], investigated the thermal performance of two phase closed thermosyphon under stationary and vibratory conditions with water and R134a as a working fluid. They carried out the experiments for filling ratio of range (40% to 80%). The thermosyphon was tested for various adiabatic lengths of (275,325 and 350mm), vibration frequency (0.0-4.33Hz) and input heat flux (160-2800 kW/m2). They obtained the result that adiabatic length of 350mm and liquid filling ratio of 50% provide the highest heat flux.

K.S. Ong and Md. Haider-E-Alahi [29], investigated performance of an R134a filled thermosyphon. They carried out the experiments to study the effects of temperature difference between bath and condenser section, fill ratio and coolant mass flow rate. The thermosyphon was of a copper material with inside and outside diameter of 25.5mm and 28.2mm respectively. The overall length of thermosyphon was 780mm (300mm-evaporator length, 300mm-condenser length). They obtained the results that the heat flux transferred increased with increasing coolant mass flow rate, fill ratio and temperature difference between bath and condenser section.

P.G. Anjankar and Dr. R.B. Yarasu [30], investigated the effect of condenser length, coolant flow rate and heat load on the performance of two-phase closed thermosyphon. The thermosyphon was a closed copper tube of length 1000mm (evaporator length-300, condenser length-450mm/400mm/350mm) and internal and external diameter of 26 and 32mm respectively. They obtained the results that thermal performance of a thermosyphon was higher at flow rate 0.0027kg/s and heat input 500W with a condenser length of 450mm.

Masoud Rahimi, Kayvan Asgary and et al. [31] studied the effect of the condenser and evaporator resurfacing on overall performance of thermosyphon. They obtained the result that by making the evaporator more hydrophilic and the condenser more hydrophobic the thermal performance of thermosyphon increases by 15.27% and thermal resistance decreases by 2.35 times compared with plane one.

Asghar Alizadehdakhel, Masoud Rahimi and et al.[32], carried out experiments to investigate the effect of various heat loads and fill ratio on the performance of thermosyphon. They obtained the results that increasing the heat load up to certain limit increases the performance of thermosyphon further increase in heat load decreases the performance of thermosyphon. Also there is an optimum value of fill ratiofor every energy input.

## III.FACTORS AFFECTING THE THERMAL PERFORMANCE OF THERMOSYPHON

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

1. Properties of working fluid
2. Filling ratio
3. Coolant flow rate
4. Coolant temperature
5. Heat load
6. Inside pressure of tube
7. Tube material properties and dimensions
8. Length of various sections(Evaporator section, Adiabatic section and Condenser section)

## IV.CONCLUSIONS FROM THE LITERATURE SURVEY

Researchers have done experimental, mathematical and computational investigation to find out various parameters affecting the thermal performance of thermosyphon and their effects. The following results are observed.

➢ Working fluid (both conventional fluid and water based nano-fluid), filling ratio, tube material and dimensions, lengths (evaporator, condenser and adiabatic section), aspect ratio, heat load, Coolant flow rate and temperature range, vaccum pressure, inclination angle ,surface tension affects the thermal performance of thermosyphon.

- Copper is found most economical metal to use as a thermosyphon tube material because it is having better thermal conductivity therefore during heat transfer it shows very small variation in temperature distribution over entire tube which is favorable condition for effective heat transfer.
- Circulation of working fluid in the tube complete due to the gravity effect, so thermosyphon can't work at horizontal position. Heat transfer performance is superior between the angles of $50^{O}$ to $90^{O}$.
- It is mandatory to evacuate the thermosyphon tube to eliminate the adverse effects of non condensable gases. So by considering the boiling point of working fluid and effect of non condensable gases, inside pressure of tube should be kept at appropriate level.
- Considering the flooding and dry-out limitations the filling ratio between the ranges of 45% to 65% show the best heat transfer performance.
- The cooling fluid temperature and flow rate can be controlled and varied as per the necessity of heat transfer.
- The surface area of condenser section should be greater than the surface area of evaporator section for the effective heat transfer . This condition can be achieved by varying aspect ratio.
- Water is found as one of the best conventional working fluid in TPCT because it has high heat transport rate for temperature range between $30^0$ to $70^{0.}$
- By Considering global warming effect due to the refrigerants having high global worming potential (GWP), it is necessary to use and research new refrigerants having less GWP for lower temperature range application.
- The water based nano fluid finds as smart working fluid in TPCT. It is found that efficiency of the TPCT increases by using water based nano-fluid with even small volume fraction of nano-particles. Nano particles have larger relative surface area compared to those of conventional particles, should not only significantly improve heat transfer capabilities, but also should increase the stability of the suspensions. Also the thermal conductivity of nano-fluid is 2 to 4 times more than the conventional fluid. But still some researchers found lot of controversies in the results in case of performance of nano-fluid in heat transfer augmentation The chaotic movement of nano particles increases fluctuation and turbulence of the fluids, which increases the heat exchange process. The effects of nanofluids like clustering of nanoparticle, coagulation should be avoided.
- Fluid vibration by sound waves is now one of the new emerging active enhancement heat transfer technique because ultrasonic sound waves induced effects such as acoustic cavitations, acoustic streaming, fluid particle oscillations, fouling reduction, intensification of phase change process, modification of bubble behavior in boiling etc., are responsible for heat transfer enhancement .This technique is also used to increase the rate of phase change process.
- Use of new efficient, conventional fluid or conventional based nano fluid to enhance the thermal performance.
- Innovation of new active or passive heat transfer enhancement techniques.

  Use of combination of active and passive heat transfer augmentation technique.

## REFERENCES


[1] M. Kannan and E.Nataranjan ,"Thermal Performance of a Two-Phase Closed Thermosyphon for waste Heat Recovery System", Journal of applied sciences ,(2010),vol10 , 413-418.

[2] S.H. Noie , "Heat transfer characteristics of a two-phase closed thermosyphon", Applied Thermal Engineering (2005) ,vol30,495–506

[3]S.H. Noie ,S. Zeinali Heris, M. Kahani and S.M. Nowee , "Heat transfer enhancement using Al2O3/water nanofluids in a two-phase closed thermosyphon.", International Journal of Heat and Fluid Flow (2009) ,vol30,700–705.

[4] Patil Aniket D and Dr. Yarasu Ravindra B, "Factors Affecting the Thermal Performance of Two Phase Closed Thermosyphon", International Journal of Emerging Technology and Advanced Engineering ,(2012), vol(2), 2250-2459.

[5] Stephen U. S. Choi, "Effects of Various Parameters on Nanofluid Thermal Conductivity", Journal of Heat Transfer, (2007), Vol. (129),617-622.

[6] S.K. Das, N. Putra,W. Roetzel, "Pool boiling characteristics of nano-fluids", International Journal of Heat and Mass Transfer ,(2003) , vol(46) ,851–862.

[7] C.Y. Tsai, H.T. Chien, P.P. Ding, B. Chan, T.Y. Luh, P.H. Chen, " Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance", Material Letters (2004),vol(58), 1461– 1465.

[8] Senthilkumar R, Vaidyanathan S, Sivaraman , "Performance Analysis of Heat Pipe Using Copper Nanofluid with Aqueous Solution of n-Butanol" ,International Journal of Mechanical and Materials Engineering ,(2010),vol(1)

[9] Paisarn Naphon, Pichai Assadamongkol, Teerapong Borirak, " Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency", International Communications in Heat and Mass Transfer ,(2008) ,vol(35),1316–1319.

[10] Sameer Khandekar, Yogesh M. Joshi and Balkrishna Mehta, "Thermal performance of closed two- phase thermosyphon using nanofluids", International Journal of Thermal Science ,(2008),vol(47), 659- 667.

[11] Gabriela Huminic Angel Huminic, "Heat transfer characteristics of a two-phase closed thermosyphons using nanofluids", Department of Thermodynamics and Fluid Mechanics, Experimental Thermal and Fluid Science , (2011) ,vol(35),550–557

[12] Saravanan M., Alagappan N. and Manikandan K., "Heat Transfer Enhancement of Two Phase Closed Thermosyphon (TPCT) using Copper Nano Fluid in Aqueous Solution of N-Butanol", International Journal of Networks and Applications, (2011), vol(2), 17-25.

[13] Mathieu Legay, Nicolas Gondrexon, "Enhancement of Heat Transfer by Ultrasound: Review and Recent Advances", International Journal of Chemical Engineering, (2011), vol(17)

[14] Kim H.T., Kim Y.G. and Kang B.H., " Enhancement of Natural Convection and Pool Boiling Heat Transfer via Ultrasonic Vibration", International Journal of Heat and Mass Transfer,(2004) ,Vol. 47, pp 2831-2840.

[15] Oh, Y.K., Park, S.H. and Cho, Y.I., "A Study of the Effect of Ultrasonic Vibrations on Phase-Change Heat Transfer", International Journal of Heat and Mass Transfer, (2002),vol.45, 4631-4641.

[16] D.W. Zhou, " Heat transfer enhancement of copper nanofluids with acoustic cavitation", International Journal of Heat and Mass Transfer ,(2004),vol.47, 3109–3117.

[17] K.A. Park and A. E. Bergle, "Ultrasonic enhancement of saturated and subcooled pool boiling", International Journal of Heat and Mass Transfer ,(1988),Vol. 31. , 664-667.

[18] K. S. Ong and W. L. Tong, "Inclination and Fill Ratio Effects on Water Filled Two-Phase Closed T hermosyphon",10th IHPS,Taipei, Taiwan,(2011).

[19] M. Karthikeyan et. al., "Thermal performance of a two phase closed thermosyphon using aqueous solution", (2010),Vol. 2, 913-918.

[20] Yoshihiro Iida and Kentarou Tsutsui , "The effects of Ultrasonic Waves on Natural Convection, Nucleate Boiling, and Film Boiling Heat transfer from a wire to a saturated liquid", Experimental Thermal and Fluid Science ,(1992),vol. 5,108-115.

[21] J. H. Jeong and Y. C. Kwon , "Effects of ultrasonic vibration on subcooled pool boiling critical heat flux", International Journal of Heat and Mass Transfer ,(2006),vol.10.1007-1012.

[22] Carlo Bartoli and Federica Baffigi, " Effects of ultrasonic waves on the heat transfer enhancement in subcooled boiling", Experimental Thermal and Fluid Science (2011) vol.35,423–432.

[23] Ho-Young Kim , Yi Gu Kim and Byung Ha Kang , "Enhancement of natural convection and pool boiling heat transfer via ultrasonic vibration", International Journal of Heat and Mass Transfer , (2004) ,vol.47,2831–2840.

[24] Sompon Wongtom, Tanongkiat Kiatsiriroat, "Effect of inclined heat transfer rate on thermosyphon heat pipe under sound wave", Asian Journal on Energy and Environment ,(2009), Vol.10,214-220.

[25]T.Theachana,V.Wongsuwan,Tanongkiat Kiatsiriroat and Atipoang Nuntaphan,**"**Performance enhancement of thermosyphon heat pipe by ultrasonic wave", *As. J. Energy Env.,(* 2009),vol.10, 76-90.

[26] Dongsheng Wen & Yulong Ding,"Experimental investigation into the pool boiling heat transfer of aqueous based γ- alumina nano-fluids", Journal of Nanoparticle Research (2005), Vol.7, pp265-274.

[27]Ganesh Ranakoti, Irtisha, Sandhya Dewangan, Siddhartha Kosti, and Rohan Nemade, "Heat Transfer Enhancement by Nano Fluids", ME642-Convective Heat and Mass Transfer, ( 2012).

[28] H.Z. Abou-Ziyan, A. Helali, M. Fatouh and M.M. Abo El-Nasr, "Performance of stationary and vibrated thermosyphon working with water and R134a", Applied thermal engineering (2001), Vol. 21, 813-830.

[29] K.S. Ong , Md. Haider-E-Alahi, "Performance of an R-134a filled thermosyphon",.Applied thermal engineering ,(2003), Vol. 23, pp2373-2381.

[30] P.G. Anjankar and Dr. R.B. Yarasu, "Experimental Analysis of Condenser Length Effect on the Performance of Thermosyphon", International Journal of Emerging Technology and Advanced Engineering ,( 2012), Vol. 2, pp 494-499.

[31] Masoud Rahimi, Kayvan Asgary and Simin Jesri, "Thermal characteristics of a resurfaced condenser and evaporator closed two phase thermosyphon". International Communications in Heat and Mass Transfer ,(2010),vol.37, pp 703–710.

[32] Asghar Alizadehdakhel, Masoud Rahimi and Ammar Abdulaziz Alsairafi, ―CFD modelling of flow and heat transfer in a thermosyphon‖. International Communications in Heat and Mass Transfer (2010), Volume 37, pp 312–318

[33] Arthur E. Bergles, "Enhancement of pool boiling", International. Journal of Refrig.eration, Vol 20, No. 8, pp. 545-551, 1997

 

[34] M. R. Sarmasti Emami, S. H. Noie and M. Khoshnoodi, “Effect of aspect ratio and filling ratio on thermal performance of an inclined two-phase closed thermosyphon”, Iranian Journal of Science &Technology, Transaction B, Engineering (2008), Vol. 32, No. B1, pp39-51.

[35] M. G. Mousa, “Thermal Performance of Thermosyphon Charged by Nanofluid for Cooling Electronic Component”, International Journal of Scientific & Engineering Research,(2011) ,Vol. 2, pp2229-5518.

[36] Shung-Wen Kang & Wei-ChiangWei , “Experimental investigation of silver nano-fluid on heat pipe thermal performance”, Applied thermal Engineering,(2006) ,vol.26,pp2377-2382.

[37]Xiang-Qi Wang, Arun S. Mujumdar , “Heat transfer characteristics of nanofluids: a review”, International Journal of Thermal Sciences , (2007) vol.46,pp1–19

 