ISSN (ONLINE): 2321-3051

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

Heat Transfer Enhancement Techniques in Two Phase Closed Thermosyphon: A Review

Faddas Nikhil A.[1], Prof. Mali Kundlik V.[2]

[1]*M.E. (Heat Power Engineering) Student, Sinhgad College of Engineering, pune, nafaddas@gmail.com*

[2]*Asst. Professor, Department of Mechanical Engineering, Sinhgad college of Engineering pune, kvmali.scoe@sinhgad.edu*

[1]*Contact:+917709245010*

Abstract

The performance of heat transfer is one of the most important research areas in the field of thermal engineering. Due to the high heat transfer effectiveness, thermosyphon has its own importance in the low temperature heat transfer. Researchers observed that geometrical factors and working solutions have significant influence on the performance of thermosyphon. Therefore the experimental 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 and inclination angle, which affects the thermal performance of thermosyphon. Also the new heat transfer enhancement techniques like use of binary mixture, use of ultrasonic wave, resurfacing and CFD analysis are enlighten. From the literature it seems to be need of binary solution, new efficient and minimum ODP and GWP refrigerants and mathematical modelling of thermal performance of thermosyphon.

Keywords: *Binary Mixture, Controllable and uncontrollable factors, Heat transfer limitations, Mathematical and computational modelling, Mechanical and surface modifications.*

1. 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.

1.1. *Thermosyphon*

Thermosyphon is an enclosed 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 which are orientation specific. They have highly used in nuclear reactor and in large electronic equipments also.

1.2. *Thermosyphon Geometry and Working Principle*

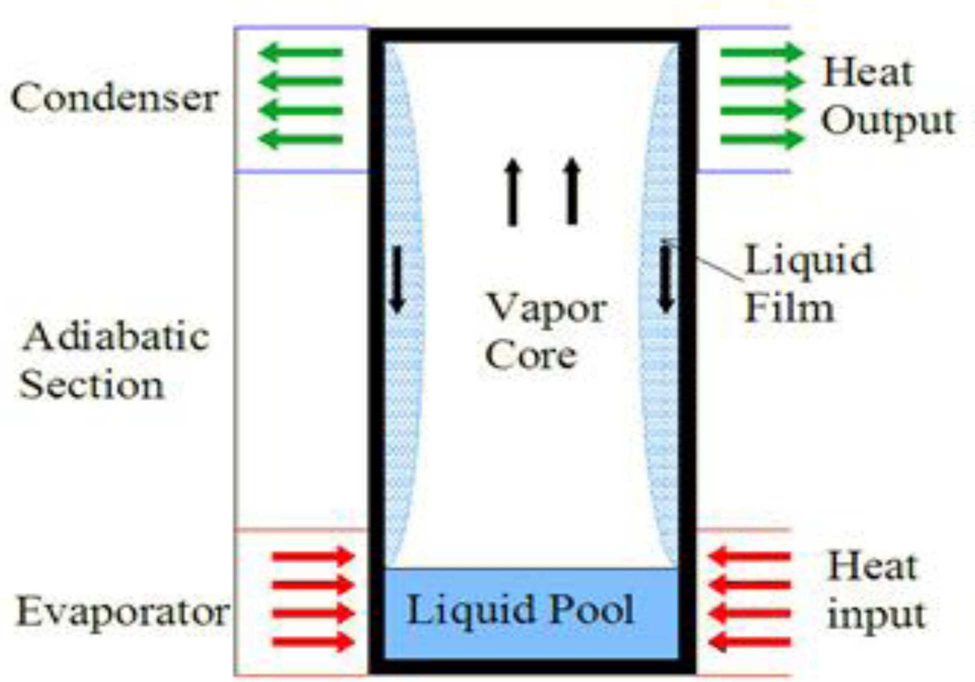

Figure 1. Two-phase closed thermosyphon working principle

A cross section of a closed two-phase thermosyphon is illustrated in Figure 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 and thus releasing the latent heat that was absorbed in the evaporator section. The heat then conducts across 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.

1.3. *Experimental Setup*

It consists of an enclosed evacuated copper tube having evaporator section at base and condenser section at the top. 8-10 thermocouples are attached on the copper tube at similar distances. Temperature indicator displays the temperature. Coil heaters or band heaters are attached to the evaporator section for heat supply and it is controlled by controlling the voltage and current. Condenser section is surrounded by concentric cylinder through with coolant flows. Flow of coolant is measured by rotameter and controlled by a valve. For initial evacuation of tube arrangement is made to attach vacuumed pump at the top and also pressure gauge is attached to measure the pressure inside the tube.

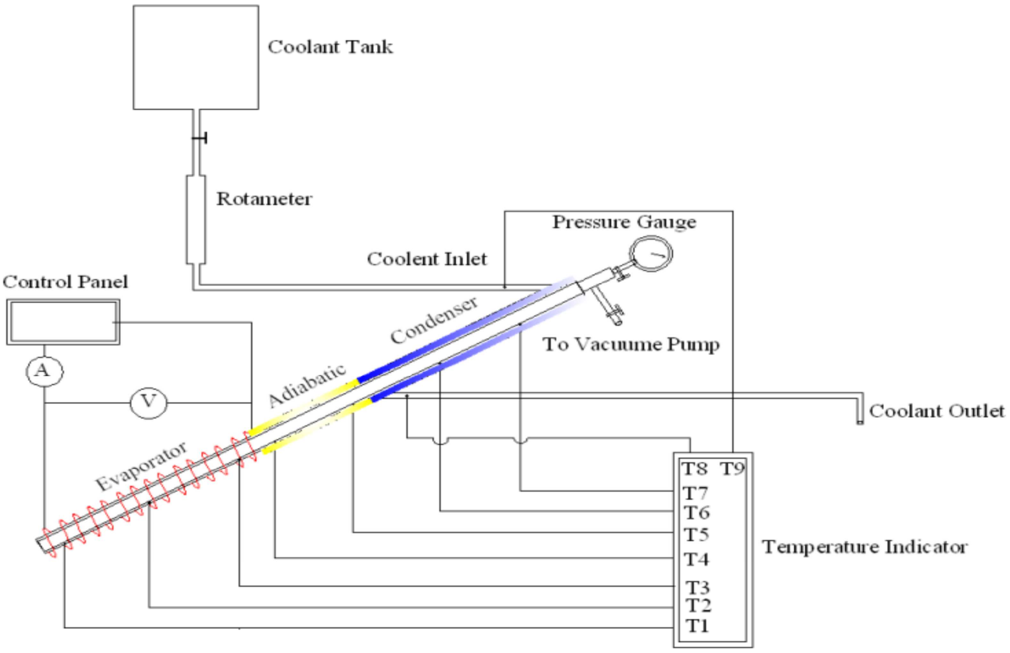

Figure 2. Experimental Setup

Following table shows the general configuration of experimental setup which may vary according to researchers requirement.

Table 1: Experimental Setup Description

Tube Material		Copper
Diameter (mm)	Internal	26
	External	32
Dimensions (mm)	Total	1000
	Evaporator	300
	Condenser	450
	Adiabatic	250
Aspect Ratio		11.53
Filling Fluid		Methanol-Ethanol Binary mixture
Inclination Angle (^{o})		50^o to 90^o
Heat Input (W)		Variable
Coolant Flow Rate (Kg/s)		Variable

2. Literature Survey

Many investigations were carried out in order to analyse and to enhance the thermal performance of thermosyphon. These are categorized into mainly three approaches.

2.1. Use of Efficient Working Fluid

In the first sort of investigation, researchers studied various working fluids as follows [1,2,3,4,5,6, 7 and 8]:

Z.Q.Long, P.Zang [1] investigated the the thermal performance of cryogenic thermosyphon charged with N2-Ar binary mixture. They have discussed heat transfer of the binary mixture in the thermosyphon theoretically by considering the mass transfer of the components. They built, an experimental setup for investigating the heat transfer performance of the cryogenic thermosyphon. They found that the N_2–Ar binary mixture can widen the operational temperature range of the cryogenic thermosyphon and it can work in the range of 64.0–150.0 K. The dry-out limit appears in the experiments for the cases with Ar fraction below 0.503. The heat transfer rate of the dry-out limit increases with the increase of Ar molar fraction until film boiling appears on the top of the condenser.

M. Karthikeyan, S. Vaidyanathan and B. Sivaraman [2] investigated the thermal performance of an inclined two phase closed thermosyphon with distilled water and aqueous solution of n-Butanol as a working fluid. They carried out the experiments for filling ratio of 60%. The thermosyphon was tested for various inclinations of 450, 600 and 900 to the horizontal. Flow rate of 0.08Kg/min, 0.1 Kg/min and 0.12 Kg/min and heat input of 40 W, 60 W and 80 W. The thermosyphon was of a copper material with inside and outside diameter of 17mm and 19mm respectively. The overall length of thermosyphon was 1000mm (400mm-evaporator length, 450mm-condenser length). They obtained the result that the thermosyphon charged with aqueous solution has the maximum thermal performance than compared to thermosyphon charged with distilled water.

H.Z. Abou-Ziyan, A. Helali, M. Fatouh and M.M. Abo El-Nasr [3] 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/m^2). They obtained the result that adiabatic length of 350mm and liquid filling ratio of 50% provide the highest heat flux.

M. R. Sarmasti Emami, S. H. Noie and M. Khoshnoodi [4] made an experimental study on the effect of aspect ratio and filling ratio on the thermal performance of inclined two-phase closed thermosyphon under normal operating conditions. They used distilled water as a working fluid. They carried out the experiments for filling ratio of range (20% to 60%) and aspect ratio of 15, 20 and 30 for an inclination angle of range (150to 900). The thermosyphon was of a copper material with inside and outside diameter of 14mm and 16mm respectively. The overall length of thermosyphon is 1000mm. They obtained the following results that the maximum thermal performance at inclination angle of 600 for all three aspect ratios and filling ratio of 45%.

K.S. Ong and Md. Haider-E-Alahi [5] 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.

Sameer Khandekar, Yogesh M. Joshi and Balkrishna Mehta [6] investigated the thermal performance of closed two-phase thermosyphon using water and various water based nanofluids (of Al_2O_3, CuO and laponite clay) as a working fluid. They observed that all these nanofluids show inferior performance than pure water.

Gabriela Humnic, Angel Huminic, Ion Morjan and Florian Dumitrache [7] 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.

A.D.Patil, Dr. R.B. Yarasu [8] performed experimental and mathematical investigation on the thermal performance of a two phase closed thermosyphon charged with distilled water. The thermosyphon was a copper tube with internal and external diameter of 26 mm and 32 mm respectively. The overall of length of thermosyphon was 1000mm (evaporator length-300mm, condenser length-450mm, adiabatic section-250). Experiments were carried out on filling ratio range of 30% to 100%, inclination angle range of 40^O to 90^O. They obtained the results that the maximum thermal performance of thermosyphon occurred at filling ratio 45% and inclination angle 50^O. Mathematical model shows an acceptable correlation between the investigated parameters.

2.2. Mechanical and surface modification

In the second sort of investigation researchers studied mechanical and surface modifications to enhance the thermal performance as follows [9, 10 and 11]:

P.G. Anjankar and Dr. R.B. Yarasu [9] 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.

H. Mirshahi and M. Rahimi [10] investigated experimentally the effect of heat loads, fill ratio and extra volume on the performance of a partial-vacuumed thermosyphon. They obtained the results that the change in heat flux, fill ratio and employing different extra volumes has a significant effect on the performance of thermosyphon.

Masoud Rahimi, Kayvan Asgary and Simin Jesri [11] 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.

2.3. Mathematical and Computational Modelling

Turning to third sort of investigation, researchers has done Numerical and computational modelling of heat transfer in thermosyphon [12 and 13]:

Asghar Alizadehdakhel, Masoud Rahimi and Ammar Abdulaziz Alsairafi [12] 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 ratio for every energy input. Experimental results were compared with CFD modelling (FLUENT^{TM} version 6.2) and there was a good agreement observed between CFD and experimental results.

S. R. Raja Balayanan, V. Velmurugan, R. Sudhakaran and N. Shenbagavinayaga Moorhy [13] have been carried out experimental and theoretical research to investigate the thermal performance of water to air thermosyphon heat pipe heat exchanger. They selected independent controllable process parameters heat input, water temperature and air velocity to carry out experimental work and correlation was developed for effectiveness of heat pipe heat exchanger. They developed mathematical model using regression coefficient method which is helpful in analyzing the performance of heat pipe heat exchanger. Mathematical model shows an acceptable correlation between the investigated parameters.

3. Heat Transfer Limitations

Limitations of heat transfer are also important parameter affecting performance of heat pipe or thermosyphon. The maximum heat transfer rate of thermosyphon is limited due to the various parameters. Each working fluid has its own limiting points. These limiting parameters are as follow.

3.1. Flooding Limitation

Flooding limitation occurs due to the interaction between the counter current liquid and vapour flows occurring at the liquid-vapour interface in the thermosyphon. Liquid- vapour interface maximum occur in the evaporator section.

3.2. Boiling Limitation

Boiling limitation is due to the large liquid filling ratio and high radial heat fluxes in the evaporator section. Under this limitation, at the critical heat flux, vapour bubbles coalesce near the pipe wall prohibiting the contact of working liquid to wall surface, resulting in the rapid increase in evaporator wall temperature. This limitation affect the thermosyphon in greater extent as applying maximum heat load to evaporator, boiling of working fluid will occur to higher limit.

3.3. Dry-out Limitation

Dry-out limitation occurs due to the relatively small filling ratio. The condensate falls down along the wall and reaches the evaporator. The condensate starts evaporating and boiling by the input power and as it comes closer and closer to the bottom, the thickness of the condensate film is thinner. It eventually dries out, so the wall temperature rises from the bottom of the evaporator at the limitation.

4. Factors Affecting 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).

5. Conclusion

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.

- 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.
- Copper (k = 386W/m-K) is having better thermal conductivity therefore during heat transfer it shows very small variation in temperature distribution of entire tube which is favourable condition for effective heat transfer. Also it is most economical metal to use as a tube material.
- For the effective heat transfer surface area of condenser section should be greater than the surface area of evaporator section. This condition can be achieved by varying diameter or length of sections.
- 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 research new refrigerants having less GWP.
- Considering the flooding and dry-out limitations the filling ratio between the ranges of 45% to 65% show the best heat transfer performance.
- 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.
- 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.
- As per the necessity of heat transfer coolant temperature and coolant flow rate can be controlled and varied.

REFERENCES

[1] Z.Q.Long, P.Zang, 2013, "Heat transfer characteristics of thermosyphon with N_2–Ar binary mixture working fluid", *International journal of heat and mass transfer*, Vol. 63, pp 204–215.

[2] M. Karthikeyan, S. Vaidyanathan and B. Sivaraman, 2010, "Thermal performance of a two Phase closed thermosyphon using aqueous solution", *International Journal of Engineering Science and Technology*, Vol. 2(5), pp 913-918.

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

[4] M. R. Sarmasti Emami, S. H. Noie and M. Khoshnoodi, ,2008, "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*, Vol. 32, No. B1, pp 39-51.

[5] K.S. Ong and Md. Haider-E-Alahi, 2003, "Performance of an R-134a filled thermosyphon", *Applied thermal engineering*, Vol. 23, pp 2373-2381.

[6] S. Khandekar, Y. M. Joshi and B. Mehta, ,2008, "Thermal performance of closed two-phase thermosyphon using Nanofluids", *International Journal of Thermal Science*, Vol. 47, pp 659-667.

[7] G. Humnic, A. Huminic, I. Morjan and F. Dumitrache, 2011, "Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles", *International Communications in Heat and Mass Transfer*, Vol. 54 , pp 656–661.

[8] Patil A.D., Dr. R.B. Yarasu, 2013, "Experimental and Mathematical Investigation on the Thermal Performance of a Two Phase Closed Thermosyphon Charged with Distilled Water", *Proceedings of the National conference on Advances in Engineering, Technology and Applied Sciences, SPANDAN-13*, pp.726-736.

[9] P.G. Anjankar and Dr. R.B. Yarasu, 2012, "Experimental Analysis of Condenser Length Effect on the Performance of Thermosyphon", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 2, Issue 3, pp 494-499.

[10] H. Mirshahi and M. Rahimi, 2009, "Experimental Study on the Effect of Heat Loads, Fill Ratio and Extra Volume on Performance of a Partial-Vacuumed Thermosyphon", *Iranian Journal of Chemical Engineering*, Vol. 6, No. 4 (autumn), IAChE.

[11] M. Rahimi, K. Asgary and S. Jesri, 2010, "Thermal characteristics of a resurfaced condenser and evaporator closed two phase thermosyphon", *International Communications in Heat and Mass Transfer*, Vol. 37, pp 703–710.

[12] A. Alizadehdakhel, M. Rahimi and A. A. Alsairafi, 2010, "CFD modelling of flow and heat transfer in a thermosyphon", *International Communications in Heat and Mass Transfer* ,Vol. 37, pp 312–318.

[13] S. R. Raja Balayanan, V. Velmurugan, R. Sudhakaran and N. S. Moorhy, 2011, "Optimization of Thermal Performance of Water to Air Thermosyphon Solar Heat Pipe Heat Exchanger using Response Surface Methodology", *European Journal of Scientific Research* ,Vol. 59, pp 451-459.