International Engineering Research Journal

Experimental Analysis of Thermosyphon Heat Pipe Using Nano Fluid.

Dhanraj Patil† and J S Gawande‡

†1Student, Department of Mechanical Engineering. JSPM's RSSOER. Savitribai Phule University, Pune, Maharashtra, India
‡2Professor and Head of Mechanical Engineering Department, JSPM's RSSOER, Savitribai Phule University, Pune, Maharashtra, India

Abstract

The present work aims at investigating the performance of wickless heat pipe heat exchanger used in waste heat recovery. This wickless heat pipe is tested with the operating fluids namely Al_2O_3 Nanofluid and distilled H_2O. The fluids were tested under variable source temperatures, mass flow rate and varying inclination angles. The prime motive of this experimentation is to determine the viability of thermosyphon heat exchanger from low temperature waste heat source. The experimentation has dealt with finding out the enhancement in the performance characteristics of thermosyphon like heat transfer rate, thermal resistance etc. at varying temperature source. The parameters varied for this purpose were , the inclination angle, the mass flow rate over the heat pipe. Also the results obtained are compared by using the two working fluids that are Al_2O_3 nanofluid and the distilled water.
Keywords— Thermosyphon, Nanofluids, Heat Transfer Rate.
text.

Keywords: *Thermosyphon, Nanofluids, Heat Transfer Rate.*

1. Introduction

Heat transfer and energy delivery play a major role in various industries including air conditioning, transportation, power generation, nuclear plants, electronic devices etc. The alteration of the surfaces of heat exchangers as well as use of better performing working fluids were among many methods implemented for enhancing the overall performance of the heat exchangers.[1].

Heat transfer in the thermosyphon takes place by the means of evaporation at evaporator section and by the means of condensation at condenser section to convey heat. The flow of fluid from the condenser to the evaporator section is made possible by the gravitational force, capillary force, or other external forces that directly act on the working fluid (i.e. electrostatic force). On the other hand, the vapour course from the evaporator to the condenser section is made possible due to the vapour pressure difference between these two sections[1].

Energy expenditure in industrial field accounts for about 70% of the total energy consumption in China , but the energy utilization ratio is only about 33%, which is 10% lower than that in developed countries. Large amount of energy is directly discharged into environment in the form of waste heat during industrial processes without any recycle. Hence, recovery and employment of industrial waste heat is of extensive importance for emission reduction and energy saving. Various methods of heat recovery and exploitation of waste heat can effectively trim down the energy consumption, and there have been a number of studies focusing on the recovery and reuse of industrial heat which is being wasted without any use. Fang et al. projected a holistic approach to the efficient employment of low-grade industrial waste heat. It showcased that the reuse of low-grade industrial waste heat to distinct heating system was practical with regards to thermal energy efficiency with environmental protection.[5]

Ersoz 2016 in his study, showed the effect of three different working fluids as methanol, distilled water and petroleum ether on the thermoeconomic analysis in the heat pipes thermosyphon which is used to heat the air is investigated.[4]

Hong 2016 in his paper studied Two Ultra-Thin Loop Heat Pipe (ULHP) prototypes with parallelogram and trapezoid evaporator configurations, which were deployed for the thermal management in a battery. The dissimilarities between their heat transfer characteristics together with the critical operating angles(15º and30º), the start-up features, the thermal resistance and also the flow unsteadiness were all kept in mind and compared with experiments gathered under multi-orientations.[1]

Khalili 2016 in studied the thermal performance of a novel sintered wick heat pipe. There are four types of common wick structures which are used in the heat pipes which includes grooved, wire mesh, sintered powder metal, and fiber/spring. Two types of sintered wick heat pipes were fabricated and tested at different filling ratios of water, and their thermal resistances in different modes were compared.[2]

R R Udaykumar 2014 [6] Pulsating heatpipe (PHP) is a passive two-phase heat transfer equipment for handling moderate to high heat fluxes typically suited for power electronics and similar applications. The performance parameters of PHP like heat transfer coefficient and thermal resistance are defined for the above conditions. Working fluids - acetone, methanol, ethanol and propanol. HP material- single loop PHP made of brass. Effect of Heat Input on Temperature difference, effect of temperature on working fluid, effect of Fill Ratio on Temperature difference, effect of working fluid on the coefficient of heat transfer, thermal resistance etc. is studied.[6].

Balkrishna Mehta 2007 studied Nanofluids, in which he typically focused on stabilized suspensions of nanoparticles normally < 100 nm in conventional fluids. The overall thermal resistance of a closed two-phase thermosyphon was determined. For that various water based nanofluids (Al_2O_3, CuO and Laponite clay) and pure water as a working fluid were used.[7]

Renjith Singh in his paper defines the thermal performance of a flat thermosyphon with one having anodised inner surface and the other without anodized inner surface. Working fluid- Acetone, inclination angles (0º , 45 º , 90 º) and fill ratios of (40%, 60% and 100%). Here the maximum improvement in heat transfer coefficients at the evaporator section and condenser section from the anodized internal surface thermosyphon is 9% and 27% respe- ctively.[9]

Mehrali showed the study of thermal performance of a grooved heat pipe using aqueous nitrogen-doped graphene (NDG) nanofluids. This study in particular concentrated on the outcome of varying NDG nanosheets concentrations, heat pipe inclination angles and input heating powers. Nanofluids shows potential as a heat exchanger fluids as they have got superior heat transfer performance because of their higher thermal conductivity. Hence he studied the heat pipe by using nanofluid and experimented its heat transfer properties by varying the inclination angles.[3]

Heat pipes are typically made using copper as it has got inherent high thermal conductivity. To manufacture lighter heat pipes without compromising thermal conductivity, alloys of aluminium, titanium and magnesium have been used but are susceptible to corrosion. These materials must be corrosion sheltered, otherwise non-condensable gases which are generated when the heat is supplied results in the corrosion of pipe, hence hampering the performance of the heat pipes. Using lighter wick materials could also be of a choice, but most advancement has been made by improving the mass transport performance of the wick rather than making it lighter.[8]

2. Nanofluids

Preparation of nanofluids is the first key step in experimental studies with nanofluids. These are produced generally by dispersing nanometer-scales solid particles into base liquids such as water, ethylene glycol(EG), oils, etc. In fusion of nanofluids, agglomeration is a key dilemma. The preparation of a nanofluid with utmost care is important because nanofluids needs some extraordinary requirements such as stable suspension, even suspension of nanoparticles, low agglomeration of particles, and no change in the chemical property of a fluid. Methods suggested for stabilizing the suspensions: (i) changing the pH value of suspension, (ii) using surface activators and/or dispersants, (iii) using ultrasonic vibration.[10].

There are two prime methods to prepare nanofluids: a two-step process and a single step method. The two-step method is more comprehensively used because nanopowders are commercially available nowadays. The nanoparticles and nanotubes are obtained as a dry powder by this process. Hence the obtained nanoparticles are then dispersed into a fluid in a next step. A variety of physical, chemical, and laser-based techniques are available for the production of the nanoparticles via this method. Aluminum oxide nanoparticles may, however, agglomerate during the drying, storage, and transportation process, leading to difficulties in the following dispersion stage of two-step method. Therefore, the stability and thermal conductivity of nanofluid are not perfect. Their stability may be further improved by controlling the pH in order to control their surface charge, modifying the surface by adding surfactants to avoid their sedimentation, and breaking down agglom- erates via ultrasonic vibration tools [11].

Various properties related to nanofluid are studied by Dhinesh Kumar Devendiran according to which we could select the appropriate for various applications by considering the given properties. Properties like thermal conductivity, viscosity, convective heat transfer, density, specific heat, pressure drop etc. are studied first.[10]

Table.1.

Properties	At 500W/44.73º C		At 1000W/59.32 º C	
	Nanofluid	Water	Nanofluid	Water
Thermal conductivity W/mK	0.81	0.64	0.83	0.65
Dynamic Viscosity Pa s	$6.59*10^{-4}$	$5.99*10^{-4}$	$5.19*10^{-4}$	$4.71*10^{-4}$
DensityKg /m3	1110	990.33	1103	983.5
Specific Heat J/KgK	4045	4178	4047	4182

Table 1: Physical properties of Al_2O_3 nanoparticle and water. [10]

3. Experimental Procedure

The experimental setup is made up of three parts, as the evaporator section, adiabatic and condenser section. In this experiment the heat transfer characteristics were measured for two different liquids (distilled water and Al_2O_3).

Also the characteristics were measured for dry run condition (without any liquid). So, the two small heat pipes were fabricated. The heat pipe was sealed at bottom and top after loading of appropriate fluid. In case of the heat pipe where liquids is used the bottom was sealed permanently and top was sealed by a removable cork, it was ensured that the working fluid operates in the vacuum created inside the thermosyphon. NiCr thermic wire was wound round the evaporator section. Power to the heater was provided from line supply.

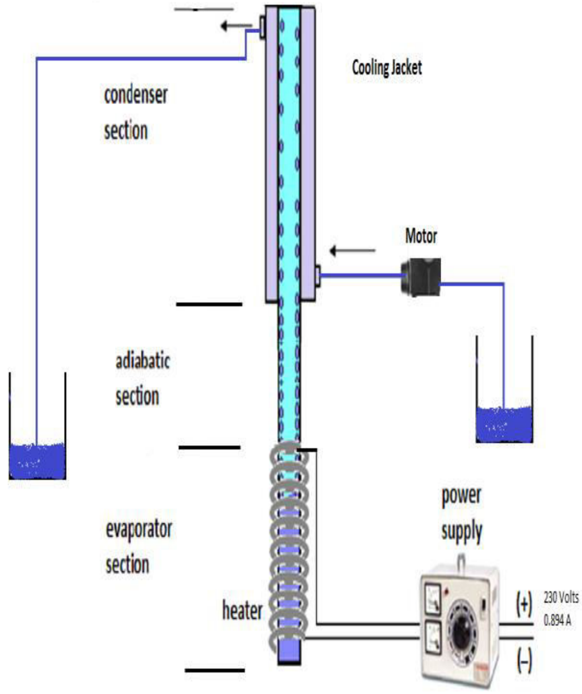

Fig-1 Experimental Setup

Water jacket is attached to the condenser section for forced convection to occur at this section. Four thermocouple wires were fixed along the exterior of thermosyphon. At the outset each thermocouple sets were fused together at the tip point and it was ensured that except the top point, they do not touch at any other points. Then they were attached with the outer surface of a thermosyphon. The other ends of the thermocouple wires were linked with the digital thermocouple reader by means of connecting wires. Thermocouples were positioned on the external surface of the heat pipe configured as, two at evaporator section, two at adiabatic section and two at condenser section. Thermocouples at each section were placed at an appropriate sections.

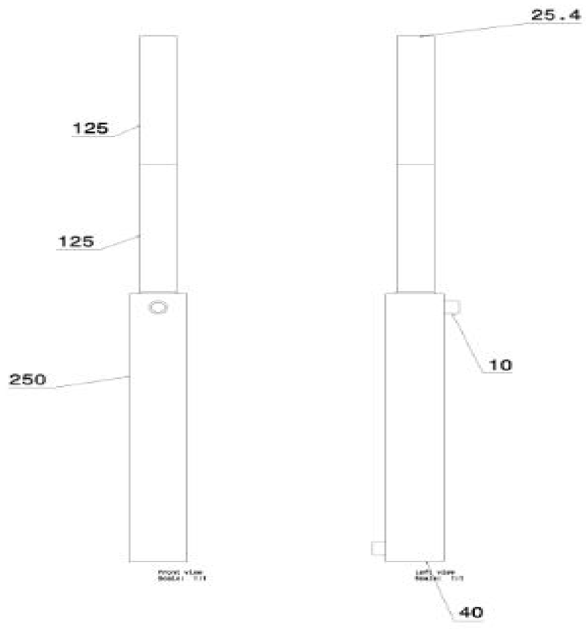

Fig 2- Thermosyphon sections

The experimental apparatus loop consists of the mixed solution test section, cold water loop and record data system. The water is chilled and controlled water temperature by temperature controller. The close-loop of cold water starts with a 5 litre storage tank. When the temperature input is given to the evaporator section, the cold water is then, pumped out of the storage tank passing through a flow controlled valve to test section (Condenser section), and then returned to the storage tank. The flow rates of the cold water is controlled with the help of flow control valve. The test section is fabricated by using straight copper tube with 40mm outer diameter, 25.4 mm inner diameter. The evaporator section of the heat pipe is fitted with the band heater which is supplied by 220V AC power supply, while the condenser section is inserted into cooling chamber. Thermocouples with K-type are implemented so as to measure the temperature of evaporator section, adiabatic section and condenser section by mounting those on the heat pipe on wall surface and fixed with insulating tape.

4. Mathematical Equations

The heat transfer rate is given by [12]

$$Q_{rec} = mC_p\,(T_{out} - T_{in}) \quad \text{............1}$$

Where,

Q_{rec}- Heat transfer rate

m- mass flow rate

T_{out}- Outlet temperature of fluid flowing through jacket

T_{in}- Inlet temperature of fluid flowing through jacket

The overall thermal resistance of a heat pipe, defined by equation, should be low, providing that it functions correctly. Hence the thermal resistance is given by

$$R_{th} = \frac{T_{evp} - T_{cond}}{Q_{rec}} \quad \text{...............2}$$

R_{th}- Thermal resistance
T_{evp}- Evaporator temperature
T_{cond}- Condenser temperature

$L_{eff} = L_{adiabatic} + 0.5[L_{evap} + L_{cond}]$ 3

The thermal conductivity can be given by -

$K_{eff} = \frac{Q_{rec} \cdot L_{eff}}{A_c \cdot (T_{evp} - T_{cond})}$ 4

K_{eff}- effective thermal conductivity

A_c- Cross section area

Let's consider the sample observation and its calculation for 30º inclination angle and 64.5 lph flow rate,

T_{in} (º C)	T_{out} (º C)	T_{evap} (º C)	T_{cond} (º C)	Time(sec)
34.8	35.6	40	37.6	36

from equation 1 we have,

$Q_{rec} = \left(\frac{64.5}{3600}\right)(773)\,(35.6 - 34.8)$

$Q_{rec} = 11.05\ W$

from equation 2 we have,

$R_{th} = \frac{40-37.6}{11.05}$

$R_{th} = 0.22\ °C/W$

from equation 3 we have,

$L_{eff} = 125 + 0.5[125 + 250]$

L_{eff} =312.5mm

Similarly the other calculations could be done.

5. Results and discussions-

The observations and calculations provides us with the distinct values of heat transfer rate with respect to time. Along with this the various other heat transfer parameters are compared to meet the objectives of gathering the result with various inclination angles, varying mass flow rate and the variability in heat transfer property with different working fluids. The graphs are plotted in order to achieve the primary objectives related to the experimentation.

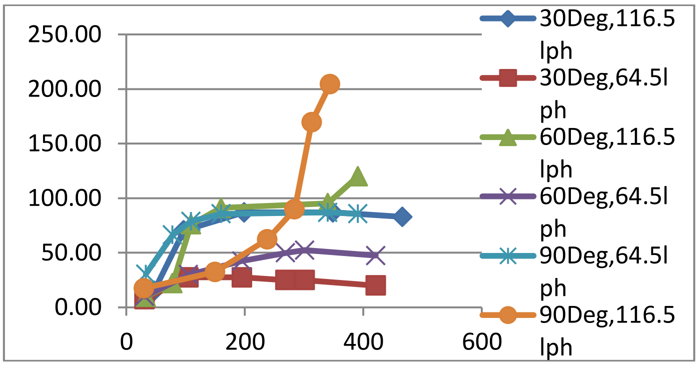

Fig-3- Variation of Heat transfer rate (Al_2O_3 Nanofluid), with inclination angle and change in mass flow rate.

In the above plot Fig-3 we have tried to show the comparison of heat transfer rate with time, here the heat transfer rate 'Q_{rec}' is taken along Y- axis and compared with the time 't' which is taken along X- axis. The observations are made by using Al2O3 nanofluid as a working fluid.

Now here let's consider the three cases-

1) Observing the plot for varying inclination angles(30 º ,60 º ,90 º) when the mass flow rate is constant at 64.5lph.

2) Observing the plot for varying inclination angles(30 º ,60 º ,90 º) when the mass flow rate is constant at 116.5lph.

3) Observing the plot for varying mass flow rate(64.5lph,116.5lph) and constant individual inclination angle.

However according to case 1 and 2 is has been observed that the heat transfer rate for the nanofluid is maximum when the thermosyphon is held perfectly vertical, hence we could comment that the maximum heat transfer rate is obtained at 90º . Along with that when the thermosyphon is inclined towards horizontal the heat transfer rate is lowered at an angle of 60 º , and further lowered at 30 º . Hence the above plot proves the influence of varying inclination angle and importance of operating the thermosyphon vertically. Now as per the case three where the mass flow rate of a fluid travelling over a thermosyphon is varied from 64.5lph to 116.5lph with constant individual inclination angle, it has been observed that the maximum heat transfer is achieved when the mass flow rate is maximum(116.5lph) . Hence this could be proved that the heat transfer rate is also dependent upon the external fluid flow rate over the thermosyphon condenser section. Higher the flow rate higher is the heat transfer rate.

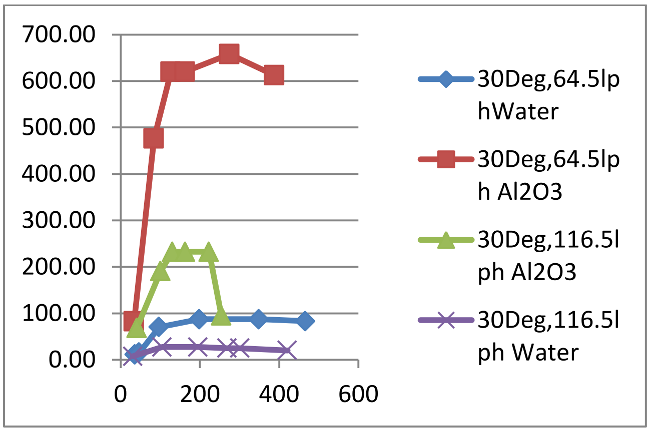

Fig-4.(a) Comparison between the working fluids(Al2O3, Water) at an inclination angle of 30 º

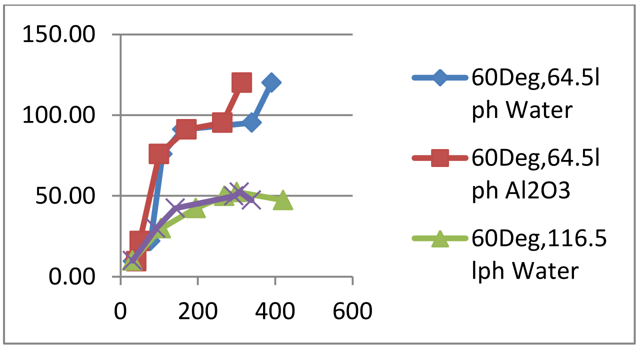

Fig-4.(b) Comparison between the working fluids(Al_2O_3, Water) at an inclination angle of 60 º

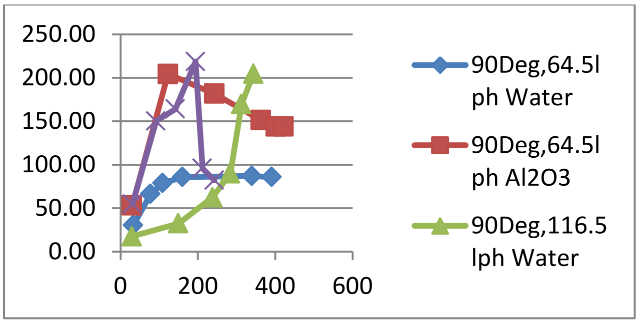

Fig-4.(c) Comparison between the working fluids(Al_2O_3, Water) at an inclination angle of 90 º

The Fig-4.(a),4.(b),4.(c) shows us the heat transfer rate characteristics between the Al_2O_3 nanofluid and distilled water. Here in the above three plots we have tried to showcase the difference in the heat transfer rate between Al_2O_3 nanofluid and distilled water. We have got the plot's of 'Q_{rec}' Vs 't'. Hence we have considered 3 cases over here-

1) Comparison between the working fluids(Al_2O_3, distilled water) at an inclination angle of 30 º .
2) Comparison between the working fluids(Al_2O_3, distilled water) at an inclination angle of 60 º
3) Comparison between the working fluids(Al_2O_3, distilled water) at an inclination angle of 90 º .

Hence as per the case 1the Al_2O_3 nanofluid performs better than the distilled water where the inclination angle is 30° and mass flow rates of 64.5 and 116.5 are considered. In case 2 we could observe that at an inclination angle of 60 ° and mass flow rate of 64.5lph Al_2O_3 nanofluid performs better than distilled water, but at 116.5 lph both Al_2O_3 nanofluid and distilled water shows near about same heat transfer rate. At last in case 3 we observe that at an angle of 90° at 64.5lph Al_2O_3 nanofluid shows better result than that of the distilled water, similarly at 116.5 lph we could see that the Al_2O_3 nanofluid shows better result at the lesser temperature input, but after certain time interval the distilled water shows better result at higher temperature.

6. Conclusion-

The two different thermosyphons are compared in which one is having Al_2O_3 nanofluid filled in it and the other is having distilled water filled in it. From the performed investigation following conclusions could be drawn.

1) The Al_2O_3 shows better heat transfer characteristics as compared to distilled water at an inclination angle of 30°, 60°,90° at 64.5lph flow rate, and 30°, 60° at 116.5lph but at 90° and 116.5lph distilled water shows better performance..
2) While considering the observations related to inclination angle for both fluids, the vertical thermosyphon or inclination angle of 90 ° proves to be efficient.
3) In the consideration of varying mass flow rate, we can conclude that, higher the mass flow rate better is the heat transfer in the thermosyphon.

References

[1] Sihui Hong, Shuangfeng Wang , Zhengguo Zhang, "Multiple orientations research on heat transfer performances of Ultra-Thin Loop Heat Pipes with different evaporator structures". International Journal of Heat and Mass Transfer 98 (2016) 415–425.

[2] M. Khalili, M.B. Shafii, "Experimental and numerical investigation of the thermal performance of a novel sintered-wick heat pipe". Applied Thermal Engineering 94 (2016) 59–75

[3] Mohammad Mehrali, Emad Sadeghinezhad, Reza Azizian, Amir Reza Akhiani, Sara Tahan Latibari, Mehdi Mehrali, Hendrik Simon Cornelis Metselaar, "Effect of nitrogen-doped graphene nanofluid on the thermal performance of the grooved copper heat pipe".Energy Conversion and Management 118 (2016) 459–473

[4] Mustafa AliErsöz a, n, Abdullah Yıldız, "Thermoeconomic analysis of thermosyphon heat pipes". Renewable and Sustainable Energy Reviews 58 (2016) 666–673

[5] Hongting Ma, Lihui Yin, Xiaopeng Shen, Wenqian Lu, Yuexia Sun, Yufeng Zhang, Na Deng, " Experimental study on heat pipe assisted heat exchanger used for industrial waste heat recovery". Applied Energy 169 (2016) 177–186

[6] R.R.Uday Kumar, Umashankar, Ch. Sreenivasa Rao, "Effect of Design Parameters on Performance of Closed Loop Pulsating Heat Pipe".Vol. 3, Issue 5, May

[7] Balkrishna Mehta and Sameer Khandekar, "TWO-PHASE CLOSED THERMOSYPHON WITH NANOFLUIDS ".14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

[8] C.W.Chan n, E.Siqueiros ,J.Ling-Chin, M.Royapoor, A.P.Roskilly, "Heat utilisation technologies: A critical review of heat pipes". Renewable and Sustainable Energy Reviews 50 (2015) 615–627

[9] R. Renjith Singh, V. Selladurai, P.K. Ponkarthik A. Brusly Solomon, "Effect of anodization on the heat transfer performance of flat thermosyphon". Experimental Thermal and Fluid Science 68 (2015) 574–581

[10] Dhinesh Kumar Devendiran , Valan Arasu Amirtham,

"A review on preparation, characterization, properties and applications of nanofluids". Renewable and Sustainable Energy Reviews 60 (2016) 21–40.

[11] M. Abdelaziz, Azza H. Ali, Hesham Elkhatib, Sameh H. Othman, "Effect of operating parameters on the transient behaviour of gravity-assisted heat-pipe using radio-chemically prepared Al2O3 nano-fluid". Advanced Powder Technology xxx (2016) xxx–xxx

[12] Min Kyu Park1 and Joon Hong Boo2*, "Thermal Performance of a Heat Pipe with Two Dissimilar Condensers for a Medium-Temperature Thermal Storage System". Journal of Applied Science and Engineering, Vol. 15, No. 2, pp. 123_129 (2012).