Experimental Analysis of Thermosyphon Heat Pipe Using Nano Fluid.

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ABSTRACT

Heat pipes and thermosyphon can be used as the most appropriate technology and most thermal effective solution due to their excellent heat transfer capability, heat transfer efficiency and structural simplicity. This work aim to investigate of experimental performance of wickless heat pipe heat exchanger charged with Al_2O_3Nanofluid under variable source temperatures, mass flow rate and varying inclination angles. The aim of this study is to investigate the feasibility of heat pipe heat exchanger from low temperature heat source. The experimentation would deal with finding out the enhancement in the performance characteristics like heat transfer rate, thermal resistance etc. at varying temperature source by varying the inclination angle of heat pipe, varying the filler ratio and by using the above Al_2O_3nanofluid and comparing the results with the other aqueous fluid

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

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1. INTRODUCTION

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

Heat pipe is a device that employs an evaporation mode of heat transfer in the evaporator section and the condensation mode in the condenser section to convey heat. The liquid flow from the condenser to the evaporator section could be produced by the gravitational force, capillary force, or other external forces that directly acting on the fluid (i.e. electrostatic force). On the other hand, the vapour flow from the evaporator to the condenser section is caused by the vapour pressure difference between these two sections[1].

Energy consumption 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 quantities of energy are directly discharged into environment as forms of waste heat during industrial processes without any recycle. Therefore, recovery and utilization of industrial waste heat is of substantial importance for energy saving and emission reduction. Different kinds of recovery and utilization of waste heat can effectively reduce energy consumption, and there have been a number of studies focusing on the recovery and reuse of industrial waste heat. Fang et al.He projected a general approach to the integrated and efficient utilization of low-grade industrial waste heat. It showed that the reuse of low-grade industrial waste heat to district heating system was practical with regards to thermal energy efficiency and environmental protection.[5]

2. LITERATURE REVIEW

Ersoz 2016, He studied the effects of different working fluids as methanol, petroleum ether and distilled water on thermoeconomic analysis in the thermosyphon heat pipes which it heats the air is examined.[4]

Hong 2016, He studied Two Ultra-Thin Loop Heat Pipe (ULHP) prototypes with different configurations such as parallelogram and trapezoid evaporator configurations were developed for battery thermal management system. The differences between their heat transfer characteristics including the critical work angles (15º&30º), the start-up features, the thermal resistances and the flow uncertainty were all explored and compared with experiments conducted under multiple orientations.[1]

Khalili 2016, He studied the Thermal performance of a novel sintered wick heat pipe. The four most commonly used wick structures used in the heat pipes are grooved, wire mesh, sintered powder metal and fiber. Two sintered wick heat pipes were fabricated and tested at different filling ratios of water and their thermal characteristics in different modes were compared.[2]

R RUdaykumar 2014 [6] Pulsating heatpipe (PHP) is a passive two-phase heat transfer device for handling moderate to high heat fluxes typically suited for power electronics and similar applications. The performance parameters of PHP like thermal resistance and heat transfer coefficient are evaluated 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 Working Fluid on Temperature difference, effect of Fill Ratio on Temperature difference, effect of working fluid on heat transfer coefficient , thermal resistance is studied in above paper[6].

Balkrishna Mehta 2007 studied Nanofluids, stabilized suspensions of nanoparticles typically < 100 nm in conventional fluids were used. The overall thermal resistance of a closed two-phase thermosyphon using pure water and various water based nanofluids (Al_2O_3, CuO and Laponite clay) as working fluids is witnessed.[7]

Renjith Singh this paper presents the thermal performance of a flat thermosyphon with and without anodized inner surface. Working fluid- Acetone, inclination angles (0º, 45 º, 90 º) and fill ratios (40%, 60% and 100%). Where the maximum enhancement in heat transfer coefficients of the evaporator and condenser in the anodized thermosyphon is 9% and 27% respectively.[9]

Mehrali showed the study of Thermal performance of a grooved heat pipe using aqueous nitrogen-doped graphene (NDG) nanofluids was analysed. This study in particular focused on the effect by varying NDG nanofuid concentrations, heat pipe inclination angles and at different input powers. Nanofluids shows potential as a heat exchanger fluids due to their better 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 due to their 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 alloys must be corrosion protected, otherwise non-condensable gas generated as a result of the corrosion will jeopardise the performance of the heat pipes. Using lighter wick materials could also be an option, but most progress has been made by improving the mass transfer performance of the wick rather than making it lighter.[8]

2. HEAT PIPE AND EXPERIMENTAL SETUP

2.2 Nano Fluids

Preparation of nanofluids is the first important step in this experiment with nanofluids. Nanofluids are produced by dispersing nanometer-scales solid particles into base liquids such as water, ethylene glycol(EG), oils, etc. In synthesis of nanofluids, agglomeration is a major problem. The delicate preparation of a nanofluid is important because nanofluids needs special requirements such as an even suspension, stable suspension, low agglomeration of particles, and no chemical change of the 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 primary methods to prepare nanofluids: a two-step process and a single step method. The two-step method is more extensively 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 methods 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. Consequently, the stability and thermal conductivity of nanofluid are not ideal. 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[23] 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]

Properties	**At 500W/44.73ºC**		**At 1000W/59.32 ºC**	
	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: Properties of Al_2O_3 nanoparticle and water. [10]

2.3 Experimental Setup

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

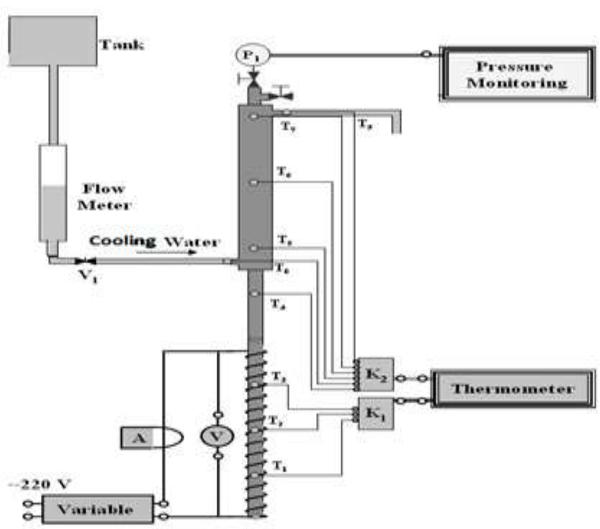

Fig-1: Experimental Setup

Also the characteristics were measured for dry run condition (without any liquid). So, two miniature 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 coiled around the evaporator section. Power to the heater was supplied from line supply. Water jacket is attached to the condenser section for forced convection to occur at this section. Six thermocouple wires were fixed along the body 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 body. The other ends of the thermocouple wires were connected with the digital thermocouple reader by means of connecting wires. Thermocouples were placed on the 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 interval of 20 mm.

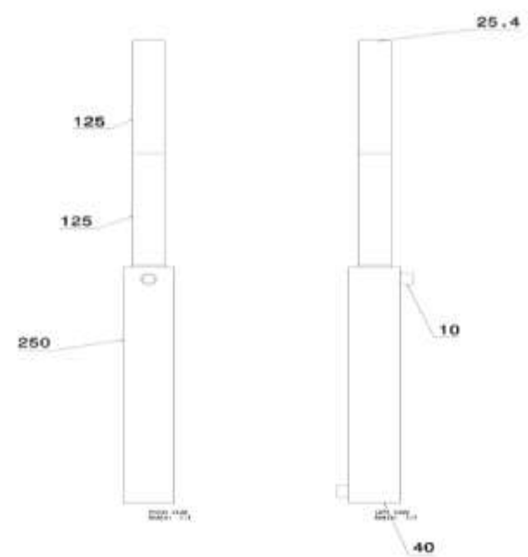

Fig 2- Thermosyphon sections

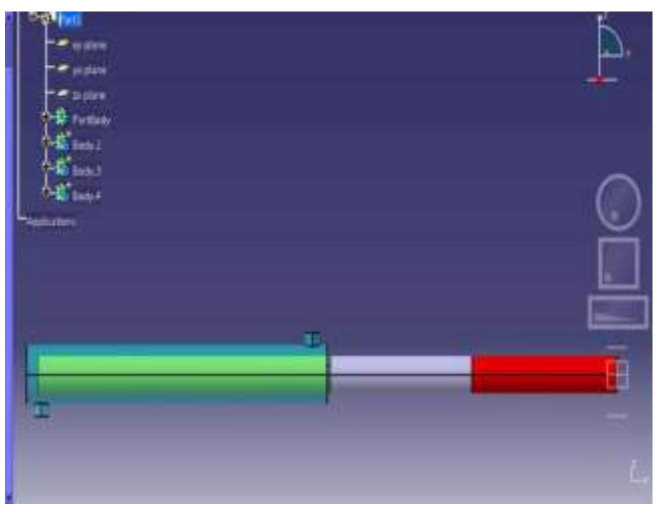

Fig 3- Thermosyphon 3D Model

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 colsd water consists of a 5 litre storage tank and a cooling coil immersed inside a storage tank. When the water temperature is reached to the desired level, the cold water is, then, pumped out of the storage tank passed through a flow controlled valve to test section (Condenser section), and return to the storage tank. The flow rates of the cold water are controlled by adjusting valve and measured by digital weight scale with the accuracy of ±0.01% of full scale. The test section is fabricated from straight copper tube with 40mm outer diameter, 20 mm inner diameter. The evaporator section of the heat pipe is inserted into the cylindrical electrical heater which is supplied by 220V AC power supply, while the condenser section is inserted into cooling chamber. Six point type K thermocouples are installed in order to measure the temperature of evaporator section, adiabatic section and condenser section by mounting on the heat pipe outside surface wall and fixed with insulating tape.

2.4 Mathematical Model

The heat transfer rate is given by [12]

$$Qrec = mCp(Te - Ti)\text{......................}1$$

Where,

Q_{rec}- Heat transfer rate

m- mass flow rate

T_e- Outlet temperature of fluid flowing through jacket

T_i- 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

$$Rth = \frac{\text{Teap} - \text{Tcond}}{Qrec}\text{........................}2$$

R_{th}- Thermal resistance

T_{evp}- Evaporator temperature

T_{cond}- Condenser temperature

The thermal conductivity can be given by -

$$Keff = \frac{\text{Qin .Leff}}{Ac(Tevap - Tcond)}\text{...........................}3$$

K_{eff}- effectivethermal conductivity

A_c- Cross section area

2.5 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.

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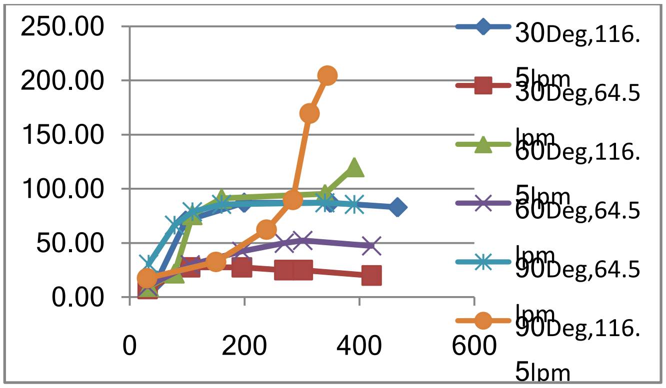

Fig-4Variation of Heat transfer rate (Al_2O_3 Nanofluid), with inclination angle & change in mass flow rate

From the above Fig-4 it is observed that the fluid is travelling over the thermpsyphon condenser section with the mass flow rate of 64.5lpm and 116.5lpm. So from the above plot, for the change in inclination angle it is observed that for the noted flow rate of 64.5lpm maximum heat transfer occurs when the inclination angle is set to 90º. Also it is noticed that when the flow rate of the fluid is varied and is set to 116.5lpm, it is observed that for the inclination angle of 90 º the heat transfer rate is better than that at the angle of 30 º & 60 º. Hence the above plot proves the influence of varying inclination angle and importance of operating the thermosyphon vertically.

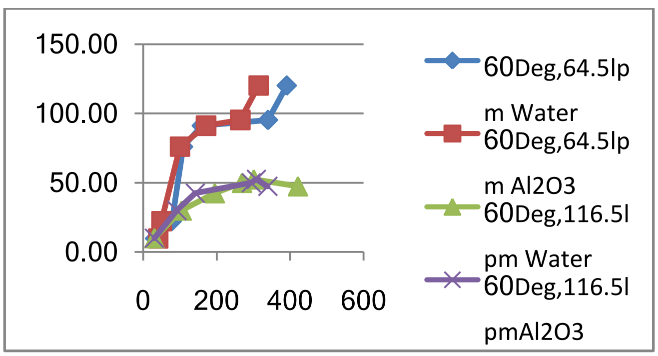

Fig-5.b Comparison between the working fluids(Al_2O_3, Water) at an inclination angle of 60 Degree

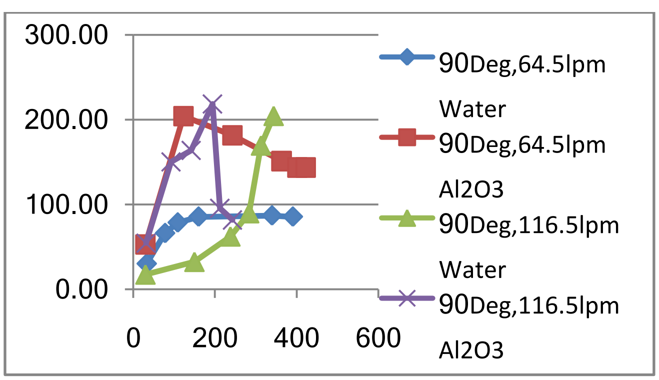

Fig-5.c Comparison between the working fluids(Al_2O_3, Water) at an inclination angle of 90 Degree

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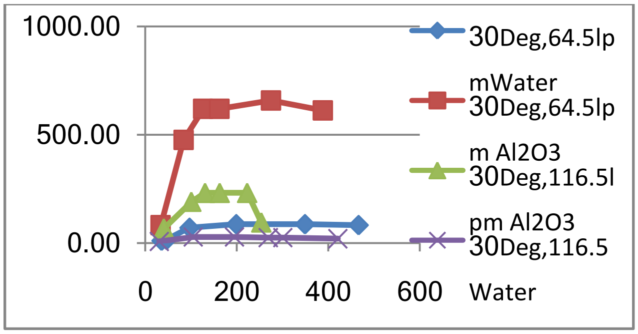

Fig-5.a Comparison between the working fluids(Al2O3, Water) at an inclination angle of 30 Degree

Along with this we could also witness that the difference in heat transfer rate for the different mass flow rates of 64.5lpm and 116.5lpm. For the inclination angle of 30º, 60º, 90º the comparison between the two mass flow rate could be seen, amongst which the better heat transfer rate is observed when the flow rate is 116.5lpm. Hence this could prove that the heat transfer rate is also dependent upon the external fluid flow rate over the thermosyphon. Higher the flow rate higher is the heat transfer rate.

3. CONCLUSION

The two different thermosyphons are compared in which one is having Al_2O_3nanofluid 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 compared to distilled water.
2) While considering the observations related to inclination angle for both fluids the vertical thermosyphon or inclination angle of 90 º proves to be efficient.
3) In the consideration of varying mass flow rate, we can conclude that, higher the flow better is the heat transfer in the thermosyphon.

ACKNOWLEDGEMENT

This paper consists of detailed experimental investigation of Thermosyphon Heat Pipe charged with nano fluid under various working conditions considering factors like tilt angle, Mass flow rate of coolant. Detailed characteristic curves are explained in the paper so that one can select the Thermosyphon heat pipe according to their application.

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