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Effect of Heat Transfer in Circular Heat Pipe with Ethanol Methanol and Al2O3 as a Nanofluid: A Review

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Abstract*:*
Heat pipes work on the principle of evaporation and condensation and thus enhances large amount of heat. A variety of working fluid and wicks are used to make a heat pipe. In recent technology attempt is made to mix the nano-powder of oxides in the working fluid which produces nanofluid and leads to increase in thermal conductivity as well as overall heat transfer coefficient and decrease in thermal resistance of nanofluids.

Different types of nanofluids are used as working media in different types of heat pipe. Thermal efficiency of heat pipe changes with mass concentration of nanoparticle as well as working fluid, inclination angle, particle size of nanoparticle, shape of nanoparticle etc.

An experimental investigation of the performance of thermosyphons charged with ethanol and methanol along with Al_2O_3 *has been carried out. The* Al_2O_3 *naoparticle are spherical in shape with 10% concentration by volume in working fluid. The copper thermosyphon was 1000 mm long with an inner diameter of 26 mm. The evaporator length was 300 mm and the condenser length was 450 mm. With ethanol methanol as the working fluid corresponding to approximately 60% filled and overfilled evaporator section in order to ensure combined pool boiling and thin film evaporation/boiling conditions.*

This review summarizes the use of Al_2O_3 *nanoparticle in heat pipe having ethanol and methanol as working fluid and thus leading to increase in heat transfer rate along with minimum temperature difference.*

Keywords*: heat pipe, nanofluid, thermal performance and thermal resistance*

1. Introduction

The thermosyphon has been proved as a promising heat transfer device with very high thermal conductance. In practice, the effective thermal conductivity of thermosyphon exceeds that of copper 200 to 500 times. A two-phase closed thermosyphon is a high performance heat transfer device which is used to transfer a large amount of heat at a high rate with minimum temperature difference. Thermosyphons make use of the highly efficient heat transfer 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 minimum 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. Due to the more heat transfer effectiveness the thermosyphon has its own importance in the low temperature difference heat transfer. They are used in many applications such as 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. 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.

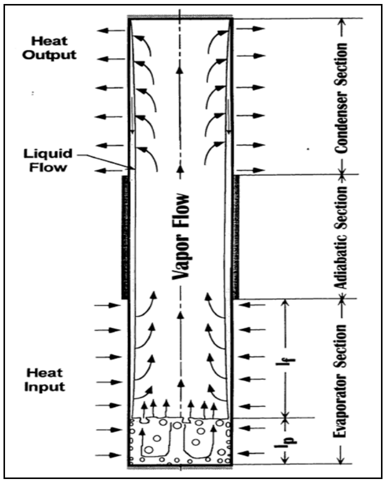

Figure 1: Two-phase closed thermosyphon working principle [13]

2. Literature Review

Elaborate study has been carried out by many researchers on the working of thermosyphon with and without nanoparticle and analysis the heat transfer performance by varying the flow rate of coolant in condenser, the aspect ratio, filling ratio, combination of various working fluids, nanoparticles with individual working fluid and with combination of various working fluid, etc. The conventional techniques of thermosyphon heat pipe have been studied from the view point of optimization and some novel strategies including inclination of thermosyphon on account of heat transfer, use of nanofluids, type of fluid used in evaporator, cooling process of condenser, etc. present great potential for extensive research. The purpose of this literature review is to go through the main topics of interest i.e. nanoparticle with ethanol and methanol mixture.

M. R. Sarmasti Emami, S. H. Noie and M. Khoshnoodi [1] 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 (15^{o} to 90^{o}). 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 60^{o} for all three aspect ratios and filling ratio of 45%.

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. 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 has being tested. 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.

K.S. Ong and Md. Haider-E-Alahi [4] investigated performance of an R134a filled thermosyphon. They carried out the experiments to study the effects of temperature difference between bath and condenser section, filling 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 transfer increases with increasing coolant mass flow rate, filling ratio and temperature difference between bath and condenser section.

Hussam Jouhara, Anthony J. Robinson [5] investigated experimentally on small diameter two-phase closed thermosyphon for four different working fluids such as water, FC-84, FC-77, and FC-3283 and analyzed that the advantage of dielectric fluids, which may be better suited for sensitive electronics cooling applications and were all found to provide adequate thermal performance up to approximately 30–50W after which liquid entrainment compromised their performance.

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.

Singh, A. K [8] studied nanofluids which are suspensions of nanoparticles in base fluids, a new challenge for thermal sciences provided by nanotechnology. Nanofluids have unique features different from conventional solid-liquid mixtures in which mm or μm sized particles of metals and non-metals are dispersed. Due to their excellent characteristics, nanofluids find wide applications in enhancing heat transfer. This study provides a review of research in this field with focus on thermal conductivity studies of nanofluids.

Saider, R., Leong K Y., Mohammad H A [9] studied the nanofluids which are potential heat transfer fluids with enhanced thermophysical properties and heat transfer performance can be applied in many devices for better performances (i.e. energy, heat transfer and other performances). In this paper, a comprehensive literature on the applications and challenges of nanofluids have been compiled and reviewed.

Xuan, Y., Li, Q [10] carried on the procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and a base liquid.

Bozorgan, N [11] analyzed the probability of collision between nanoparticles and the heat exchanger wall increases, due to using higher concentration of coolants, the total heat transfer coefficient increases. Consequently, in this paper, heat transfer coefficient, total heat transfer coefficient, friction factor, pressure drop and pumping power for Al_2O_3/Ethylene glycol and TiO_2/Ethylene glycol nanofluid coolants in the double-tube heat exchanger are calculated.

Mapa, L. B., Mazhar S [12] calculated the theoretical heat transfer rates using existing relationships in the literature for conventional fluids and nano fluids. Experiments were conducted to determine the actual heat transfer rates under operational conditions using nanofluids and the heat transfer enhancement determined compared to fluids without nanoparticles.

3. Experimental Setup

Experimental setup of two phase closed thermosyphon is illustrated in Fig.2. It consists of an enclosed evacuated copper tube having evaporator section at lower side and condenser section at the upper side. 10 thermocouples are attached on the copper tube at similar distances, and the positions of thermocouples are selected such that entire temperature distribution of thermosyphon tube should be covered. Temperature indicator displays the temperature of the thermocouples attached to the copper tube. 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 which coolant flows. The coolant flow is varied by a controlled 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. Evacuation is necessary to eliminate the effect of non condensable gases.

Following table shows the general configuration of experimental setup which may vary according to researchers requirement. The liquid is 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 the horizontal position.

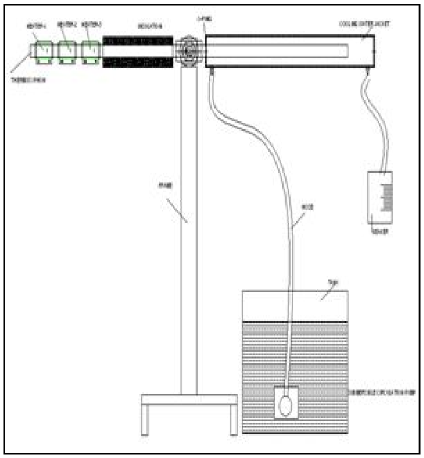

Figure 2: Schematic Diagram of Experimental Setup

Tube Material		**Copper**
Inside Pressure		0.01bar
Diameter (mm)	Internal	26
	External	32
Dimensions (mm)	Total	1000
	Evaporator	300
	Condenser	450
	Adiabatic	250
Aspect ratio		Variable
Filling Fluid		Ethanol and methanol mixture (3:2 ratio)
Filling ratio (%)		60%
Heat Input (W)		Variable
Coolant flow rate (kg/s)		Variable
Thermocouple		K type
Nanoparticle		Al_2O_3
Nanoparticle concentration		10% by volume

Table 1: General Experimental Setup Description

4. Heat Transfer Limitations

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.

- *Flooding Limitation:* This limitation is due to the interaction between the counter current liquid and vapour flows occurring at the liquid-vapour interface in the thermosyphon.
- *Boiling Limitation:* This limitation is due to the large liquid fill 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.
- *Dry-out Limitation:* This limitation is 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.

5. Theory of Heat Transfer in Nanofluids

5.1. Introduction

Various techniques have been proposed to enhance the heat transfer performance of fluids. Researchers have also tried to increase the thermal conductivity of base fluids by suspending micro or larger sized solid particles in fluids since the thermal conductivity of solid is typically higher than that of liquids, as seen from Table 2.

		Material	**Thermal conductivity (W/m K)**
1.	Metallic solids	copper	401
		aluminium	237
2.	Nonmetallic solids	silicon	148
		alumina (Al_2O_3)	40
3.	Metallic liquids	sodium	72.3
4.	Nonmetallic liquids	water	0.613
		ethylene glycol (EG)	0.253
		engine oil (EO)	0.145

Table 2: Thermal conductivities of various solids and liquids [8]

The mixture of suspended nanoparticles in a base liquid is usually referred to as a nanofluid. Nanofluids are a relatively new class of fluids which consist of a base fluid with nano-sized particles (1–100 nm) suspended within them. These particles, generally a metal or metal oxide, increase conduction and convection coefficients, allowing for more heat transfer. Addition of nanoparticles in liquid remarkably enhances energy transport process of the base liquid. Nanofluids have some unique features that are quite different from conventional two-phase flow mixtures in which µm or mm particles are suspended. Compared to a conventional two-phase mixture, the nanofluid has higher thermal conductivity; it does not block flow channels and induces a very small pressure drop. Solid particles are added as they conduct heat much better than a liquid. The large surface area of nanoparticles improves the heat transfer capabilities and also increases the stability of the suspensions. Nanofluids can improve abrasion-related properties as compared to the conventional solid/fluid mixtures. In addition, nanoparticles resist sedimentation, as compared to larger particles, due to random motion and inter particle forces and possess much higher surface area which enhances the heat conduction of nanofluids since heat transfer occurs on the surface of the fluid.

Three properties that make nanofluids promising coolants are:

- Increased thermal conductivity,
- Increased single-phase heat transfer and
- Increased critical heat flux.

Therefore, exploiting the unique characteristics of nanoparticles, nanofluids are created with two features very important for heat transfer systems:

- Extreme stability and
- Ultra-high thermal conductivity.

This new class of heat transfer fluids has shown several distinct properties with large enhancements in thermal conductivity as compared to the base liquid, temperature and particle size dependence, reduced friction coefficient, and significant increase in critical heat flux [1].

Nanofluids have great potential for thermal management and control involved in a variety of applications such as:

- Electronic cooling,
- Micro electro mechanical systems (MEMS) and
- Spacecraft thermal management.
- Airplanes,
- Cars,

6. Thermal Conductivity Models

Thermal conductivity of nanofluids is found to be an attracting characteristic for many applications. It represents the ability of material to conduct or transmit heat. Increase in thermal conductivity depends on nanoparticle material, size and concentration. Nanoparticles have a large surface area-to-volume ratio; a 1 nm spherical particle has a surface area-to-volume ratio 1000 time greater than that of a 1 μm particle. Resistance becomes important for such large surface areas.

7. Factors Affecting the Thermal Performance of Thermosyphon

From the literature survey it is observed that following factors affects the thermal performance of thermosyphon. These factors are classified in the terms of controllable and uncontrollable factors. Controllable factors are the factors which can be controlled or variable during the experimentation and uncontrollable factors cannot be controlled or varied during the experimentation.

So for the experimentation the group of controllable and uncontrollable factors can be studied for best result.

CONTROLLABLE FACTORS	UNCONTROLLABLE FACTORS
Filling fluid	Tube material
Coolant flow rate	Tube dimensions
Coolant temperature	Working fluid
Inclination angle	Aspect ratio
Heat load	
Inside pressure	

Table 3: Controllable and uncontrollable factors [1]

8. 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, nanoparticle type, concentration of nanoparticle, size of nanoparticle, shape of nanoparticle affects the thermal performance of thermosyphon.
- Copper (k = 386W/mK) 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.
- Considering the flooding and dry-out limitations the filling ratio between the ranges of 45% to 65% shows 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.

- As per the necessity of heat transfer; coolant temperature and coolant flow rate can be controlled and varied.

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