Experimental Investigation of Heat Transfer Enhancement Techniques in Two Phase Closed Thermosyphon

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Abstract— The thermal performance of an inclined two phase closed thermosyphon with different working fluid has been investigated experimentally in this paper. Distilled water and Binary mixture of ethanol and methanol 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 20.5 mm and an outer diameter of 22.5 mm was employed. Thermosyphon was charged with 60% of the working fluid and was tested with an evaporator length of 300 mm and condenser length of 450 mm. The thermosyphon was tested for various inclinations of 45˚, 60˚ and 90˚ to the horizontal. Flow rate of 4 Kg/hr, 12 Kg/hr and 20 Kg/hr and heat input of 40 W, 60 W and 80 W were taken as input parameters. The thermal performance of binary mixture charged two phase closed thermosyphon was out performed the distilled water in both heat transfer and temperature distribution.

Keywords: Two phase closed thermosyphon, Heat transfer limitations, Binary mixture, Heat load, Coolant flow rate, Inclination angle, Efficiency

I. INTRODUCTION

Energy is an important part of most aspects of daily life. The quality of life and even its substance depends on the availability of energy. Hence energy plays a vital role in day to day life as well as in heat transfer applications. Due to the human need for energy, a more efficient way of using it is a major challenge in the scientific community. The heat pipe and the thermosyphon specially designed by the engineers for transferring heat from a distance. The thermal performance of thermosyphon is one the most important part of these types of investigation in the field of heat transfer.

1.1. Heat Transfer Enhancement Techniques:

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

- Passive techniques
- Active techniques
- Compound techniques

1.1.1. Passive Techniques:

These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behaviour (except for extended surfaces) which also leads to increase in the pressure drop.

1.1.2. Active Techniques:

These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer, like mechanical aids, surface vibration, fluid vibration, suction, etc.

1.1.3. Compound Techniques:

A compound is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo- hydraulic performance of a heat exchanger.

1.2. 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.

1.3. Thermosyphon Geometry and Working Principle:
A cross section of a closed two-phase thermosyphon is illustrated in Fig. 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.

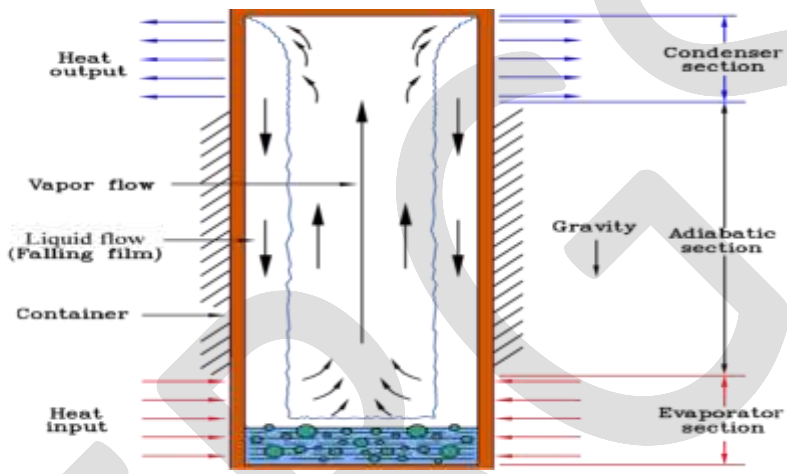

Fig.1: Two-phase closed thermosyphon working principle

1.4. Applications:
- Radiators
- Aerospace
- High tech electronics
- Solar system
- Satellite thermal control
- Waste heat recovery

1.5. Advantages:
- Passive heat exchange with no moving parts.
- Relatively space efficient.
- The cooling or heating equipment size can be reduced in some cases.
- The moisture removal capacity of existing cooling equipment can be improved.
- No cross contamination between streams.

II. REVIEW OF WORK CARRIED OUT

Many investigations were carried out in order to analyse and to enhance the thermal performance of thermosyphon. These are as follows.
Grover [1] (Los Alamos Laboratory, USA) introduced the term heat pipe in 1964. The two-phase closed thermosyphon used in this study is essentially a gravity-assisted wickless heat pipe, which is very efficient for the transport of heat with a small temperature difference via the phase change of the working fluid. It consists of an evacuated-closed tube filled with a certain amount of a suitable pure working fluid. The simple design, operation principle, and the high heat transport capabilities of two-phase closed thermosyphons

are the primary reasons for their wide use in many industrial and energy applications. Since there is no wick material, the thermosyphon is simpler in construction, smaller in thermal resistance, and wider in its operating limits than the wicked heat pipe.

Z. Q. Long, P. Zang [2] investigated 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 [3] 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 45˚, 60˚and 90˚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 [4] 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.

Negishi and Sawada [5] made an experimental study on the heat transfer performance of an inclined two-phase closed thermosyphon. They used water and ethanol as working fluids. The highest heat transfer rate was obtained when the filling ratio (ratio of volume of working fluid to volume of evaporator section) was between 25% and 60% for water and between 40% and 75% for ethanol. The inclination angle was between 20° and 40° for water, and more than 5° for ethanol.

M. R. Sarmasti Emami, S. H. Noie and M. Khoshnoodi [6] 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˚to 90˚). 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˚for all three aspect ratios and filling ratio of 45%.

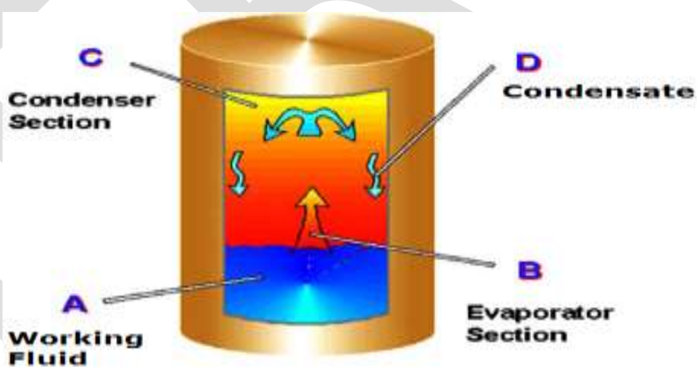

Fig.2: Schematic diagram of a two-phase closed thermosyphon

K.S. Ong and Md. Haider - E - Alahi [7] 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 [8] 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 [9] 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.
P. G. Anjankar and Dr. R. B. Yarasu [10] 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- 300mm, 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 [11] 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 [12] 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 Ammar Abdulaziz Alsairafi [13] 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 [14] 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.

III. CHARACTERISTIC OF THERMOSYPHON AND WORKING FLUID

As an effective heat conductor, thermosyphon can be used in situations when a heat source and a heat sink need to be placed apart, to aid heat conduction of a solid, or to aid heat spreading of a plane. However, not every thermosyphon heat pipe is suitable for all applications. For that reason and to develop an experimental model the following need to be considered while designing heat pipes.

A. Heat transfer limitations of the thermosyphon:

Thermosyphon heat pipe performance and operation are strongly dependent on shape, working fluid and wick structure. Certain heat pipes can be designed to carry a few watts or several kilowatts, depending on the application. The effective thermal conductivity of the heat pipe will be significantly reduced if heat pipe is driven beyond its capacity. Therefore, it is important to assure that the heat pipe is designed to transport the required heat load safely. But during steady state operation, the maximum heat transport capability of a heat pipe is governed by several limitations, which must be clearly known when designing a heat pipe. There are five primary heat pipe transport limitations.

• **Viscous Limit:**

At low operating temperatures, viscous forces may be dominant for the vapour moving flow down the heat pipe. For a long liquid-metal heat pipe, the vapour pressure at the condenser end may reduce to zero. The heat transport of the heat pipe may be limited under this condition. The vapour pressure limit (viscous limit) is encountered when a heat pipe operates at temperatures below its normal operating range, such as during start up from the frozen state. In this case, the vapour pressure is very small, with the condenser end cap pressure nearly zero.

• **Sonic Limit:**

The rate at which vapours travels from evaporator to condenser known as sonic limit. The evaporator and condenser sections of a thermosyphon represent a vapour flow channel with mass addition and extraction due to the evaporation and condensation, respectively. The vapour velocity increases along the evaporator and reaches a maximum at the end of the evaporator section. The limitation of such a flow system is similar to that of a converging-diverging nozzle with a constant mass flow rate, where the evaporator exit corresponds to the throat of the nozzle. Therefore, one expects that the vapour velocity at that point cannot exceed the local speed of sound. This choked flow condition is called the sonic limitation. The sonic limit usually occurs either during heat pipe start up or during steady state operation when the heat transfer coefficient at the condenser is high. The sonic limit is usually associated with liquid-metal heat pipes due to high vapour velocities and low densities. When the sonic limit is exceeded, it does not represent a serious failure. The sonic limitation corresponds to a given evaporator end cap temperature. Increasing the evaporator end cap temperature will increase this limit to a new higher sonic limit. The rate of heat transfer will not increase by decreasing the condenser temperature under the choked condition. Therefore, when the sonic limit is reached, further increases in the heat transfer rate can be realized only when the evaporator temperature increases. Operation of heat pipes with a heat rate close to or at the sonic limit results in a significant axial temperature drop along the heat pipe.

• **Entrainment Limit:**

This limit occurs due to the friction between working fluid and vapour which travel in opposite directions. A shear force exists at the liquid-vapour interface since the vapour and liquid move in opposite directions. At high relative velocities, droplets of liquid entrained into the vapour flowing toward the condenser section. If the entrainment becomes too great, the evaporator will dry out. The heat transfer rate at which this occurs is called the entrainment limit. Entrainment can be detected by the sounds made by droplets striking the condenser end of the heat pipe. The entrainment limit is often associated with low or moderate temperature heat pipes with small diameters, or high temperature heat pipes when the heat input at the evaporator is high.

• **Capillary Limit:**

It is the combination of gravitational, liquid and vapour flow and pressure drops exceeding the capillary pumping head of the heat pipe wick structure. The main cause is the heat pipe input power exceeds the design heat transport capacity of the heat pipe. The problem can be resolved by modifying the heat pipe wick structure design or reduce the power input.

• **Boiling Limit:**

The rate at which the working fluid vaporizes from the added heat. If the radial heat flux in the evaporator section becomes too high, the liquid in the evaporator section boils and the wall temperature becomes excessively high. The vapour bubbles that form near the pipe wall prevent the liquid from wetting the pipe wall, which causes hot spots, resulting in the rapid increase in evaporator wall temperature, which is defined as the boiling limit. However, under a low or moderate radial heat flux, low intensity stable boiling is possible without causing dry out. It should be noted that the boiling limitation is a radial heat flux limitation as compared to an axial heat flux limitation for the other heat pipe limits. However, since they are related though the evaporator surface area, the maximum radial heat flux limitation also specifies the maximum axial heat transport. The boiling limit is often associated with heat pipes of non-metallic working fluids. For liquid-metal heat pipes, the boiling limit is rarely seen.

B. Effect of Fluid Charge:

Filled ratio is the fraction (by volume) of the heat pipe which is initially filled with the liquid. There is two operational filled ratio limits. At 0% filled ratio, a heat pipe structure with only bare tubes and no working fluid, is pure conduction mode heat transfer device with a very high undesirable thermal resistance. A 100% fully filled heat pipe is identical in operation to a single phase thermosyphon. When the charge amount was smaller, there was more space to accommodate vapour and make the pressure inside heat pipe become relatively lower. It helped working fluids undergo vaporization and enhance its heat transfer performance. Therefore, the most proper filled ratio is between 40% and 60%.

C. Working Fluid:

- **Binary mixture:**

From the literature review, it is found that various researches has been done on various working fluid solutions like water, distilled water, butanol, ethanol, etc., refrigerant like R-12, R-22, R-134a, FC-72, FC-77, FC-84, etc. and nanoparticles such as Al2O3, Ag2O3 and Fe2O3, etc. In many investigation of thermosyphon, it is seen that water as a working fluid has a better performance than other solutions. But because of its high boiling point it cannot be used for cold temperature regions. By using other solutions as a working fluid does not get better thermal performance than water. So it is need of time to use binary mixture of various solutions to get better thermodynamic property for using working fluid in two phase closed thermosyphon .

- **Ethanol-Methanol Mixture:**

As far as selection of working fluid for thermosyphon is concerned, first go through various thermodynamic properties of ethanol and methanol.

Table.1: Properties of ethanol and methanol:

Property	**Methanol CH3OH**	**Ethanol C2H5OH**
Molecular Weight	32	46
Boiling point (˚C)	65	78
Melting point (˚C)	-98	-144
Useful temperature range (˚C)	10 to 130	0 to 130
Thermal Conductivity at 300K (W/m-K)	0.202	0.171
Latent heat of vaporization (kJ/kg)	1100	846

In this experiment we used ethanol and methanol ratio 60:40 (by volume) because at this ratio these two solutions are completely soluble with each other.

Table.2: Properties of ethanol-methanol mixture:

Property	Ethanol-Methanol Mixture
Boiling point (℃)	72.8
Melting point (℃)	-125.6
Useful temperature range (℃)	0 to 100
Thermal conductivity at 300 K (W/m-K)	0.1834
Latent heat of vaporization (kJ/kg)	947.6

These thermodynamic properties are useful for the thermosyphon as a working fluid in 0℃ to 100℃ temperature applications. Hence ethanol-methanol mixture was selected for the experimental assessment of the thermosyphon as a working fluid.

IV. EXPERIMENTAL SETUP DESCRIPTIONS

It consists of an enclosed evacuated copper tube having evaporator section at base and condenser section at the top. 9 thermocouples are attached on the copper tube at similar distances. Temperature indicator displays the temperature. . The uniform heat flux wire type heater is fabricated from nickel-crome wire. This wire is connected in series with dimmer stat in order to supply the same amount of heat to nickel-crome wire. Nickel-crome coil 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. The range of rotameter is 0-20LPM. 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.

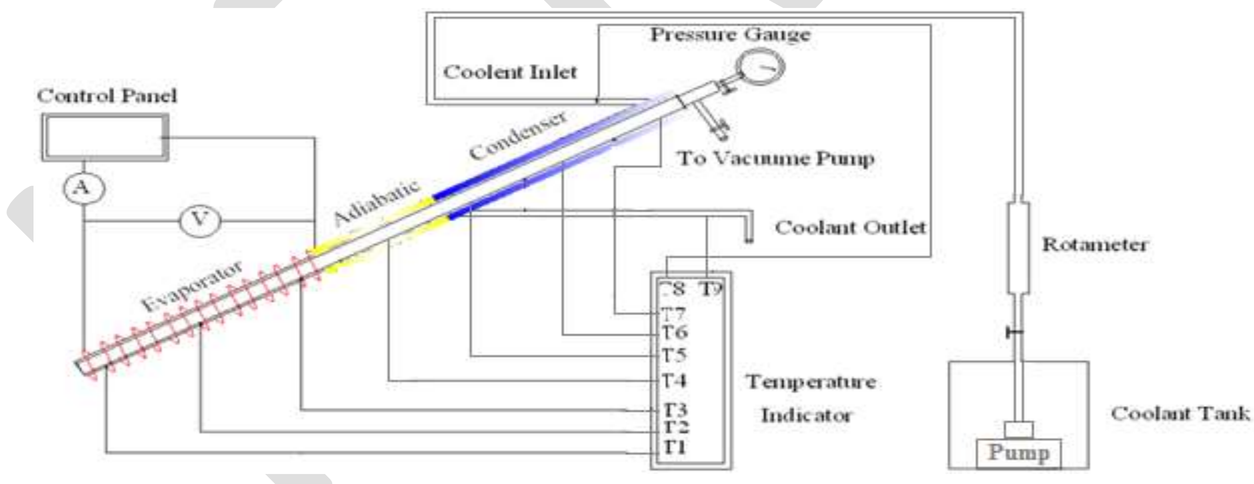

Fig.3: Schematic diagram of thermosyphon experimental setup

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

Table.3: Experimental Setup Description:

Tube Material		Copper
Diameter (mm)	Internal	20.5
	External	22.5
Dimensions (mm)	Total	1000
	Evaporator	300
	Condenser	450

	Adiabatic	250
Aspect Ratio (Le/Di)		14.63
Filling Ratio		60 %
Working Fluid		Mixture Of Methanol-Ethanol and Distilled Water
Inclination Angle (^{o})		45, 60, 90
Heat Input (W)		40, 60, 80
Coolant Flow Rate (Kg/hr)		20, 12, 4

- **Factors for experimental analysis:**

Coolant flow rate:

It is also important parameter which affects the thermal performance of thermosyphon to large extent. Coolant used in this experimentation is water, because water has maximum ability to gain or lose the heat from the system. At the condenser part working fluid is condensed due to which heat is released to the atmosphere. For that purpose, condenser section is enclosed by another coaxial copper tube. Upper and lower ends of this external tube are perfectly closed. In this experimentation we have used various coolant flow rate which are 4kg/hr, 12 kg/hr, and 20 kg/hr. During experimentation it was found that at lower coolant flow rate, heat transfer efficiency of thermosyphon is maximum and at higher coolant flow rate, heat transfer efficiency was minimum. This is because at lower coolant flow rate, velocity of coolant is minimum inside the outer shell of the condenser due to which there is enough time to exchange heat from the working fluid to the coolant.

Inclination angle:

It is also important factor which affect thermal performance of thermosyphon to great extent. The lower end of the thermosyphon tube was heated causing the liquid to vaporise and the vapour to move to the cold end of the tube where it is condensed. The condensate is returned to the hot end by gravity. This is why thermosyphon is kept vertical i.e, 90° with horizontal. Experimentation also includes study at various inclination angles to evaluate thermal performance. At various inclination angles and at various heat loads thermal performance is varying. So after experimentation we got best configuration factor of inclination angle and heat load which is responsible for higher thermal performance.

Heat Load:

Heat load is given to the evaporator section of the thermosyphon. After applying heat, working fluid get vaporize in the evaporator. But heat load is dependent on working fluid. It defines boiling limit of the working fluid. If the boiling point of the working fluid is higher near about 100° C, then heat load can be applied from 100° C to the point where maximum fluid will evaporate. In this experimental model, we have used binary mixture of ethanol-methanol and distilled water as a working fluid. Thermodynamic properties of ethanol and methanol are shown in Table 2. Ethanol and methanol has lower boiling points than water and under vacuum mixture gain low boiling point. So for experimentation we have selected heat load range of 40W, 60W and 80 W.

- **Experimentation Parameters:**

Experimentation was carried on the two phase closed thermosyphon. Working fluid is important parameter in the experimentation. Ethanol-Methanol binary mixture and Distilled Water was used as a working fluid. Other parameters and its description as follows.

Table.4: Experimentation parameters

Parameter	**Description**
Heat load (W)	40, 60 and 80
Inclination angle with horizontal axis (˚)	45, 60 and 90
Coolant flow rate (kg/hr)	4, 12 and 20
Aspect ratio	14.63
Filling ratio	60% (60% Ethanol and 40% Methanol) and 60% Distilled Water

V. RESULTS AND DISCUSSION

A. Temperature distribution along the thermosyphon:

Fig. 4 to 12 shows distance Vs surface temperature along the thermosyphon. When heat input increases, the surface temperature of distilled water and binary mixture used in the thermosyphon increases. The surface temperature of thermosyphon with binary mixture is lower than the distilled water.

B. Effect of thermosyphon efficiency:

Fig. 13 to 15 shows the heat input Vs efficiency of thermosyphon for various heat input and flow rates for both distilled water and binary mixture. The efficiency of thermosyphon gives better results for binary mixture than the distilled water all inclinations, heat input and flow rates. For vertical position of thermosyphon, the efficiency is higher than the other for inclination. The lower inclination reduces the efficiency due to the obstruction of vapour with condensate return from the condenser. The efficiency is higher for 80 W heat input than the 40 W and 60 W heat inputs.

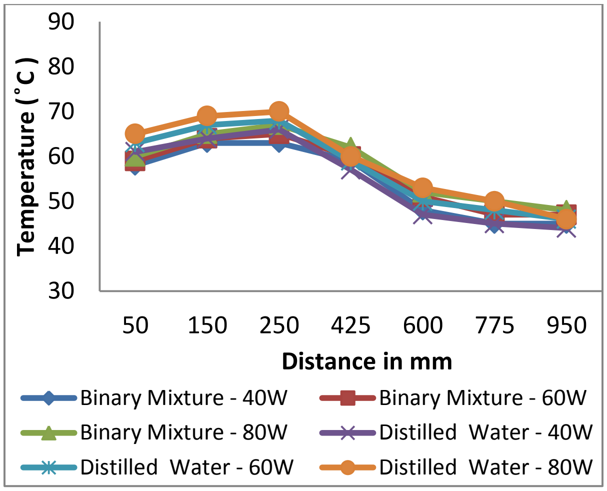

Fig.4: Flow rate 20Kg/hr inclination 90°

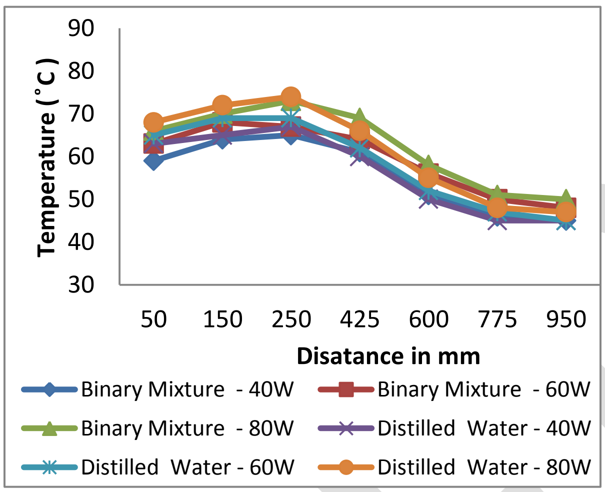

Fig.5: Flow rate 12Kg/hr and inclination 90°

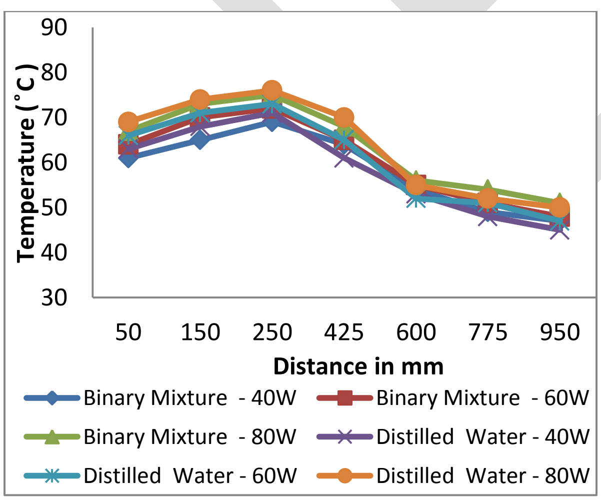

Fig.6: Flow rate 4Kg/hr and inclination 90°

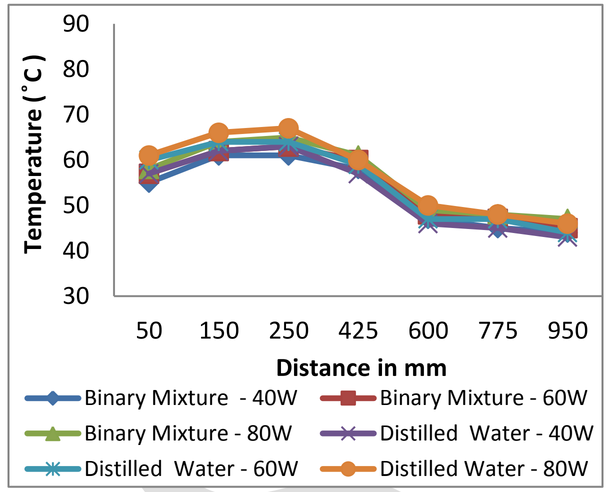

Fig.7: Flow rate 20Kg/hr and inclination 60°

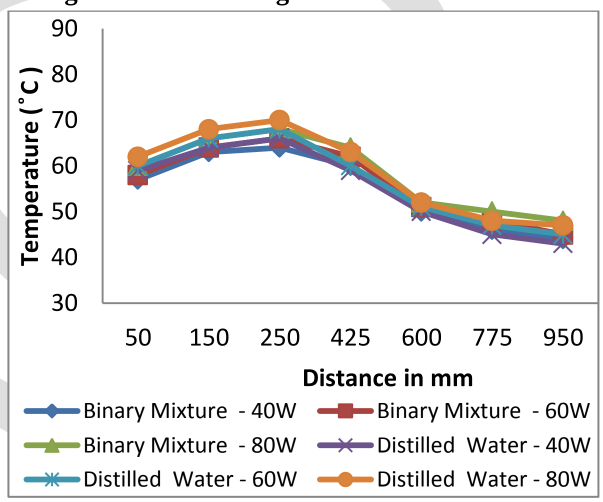

Fig.8: Flow rate 12Kg/hr and inclination 60°

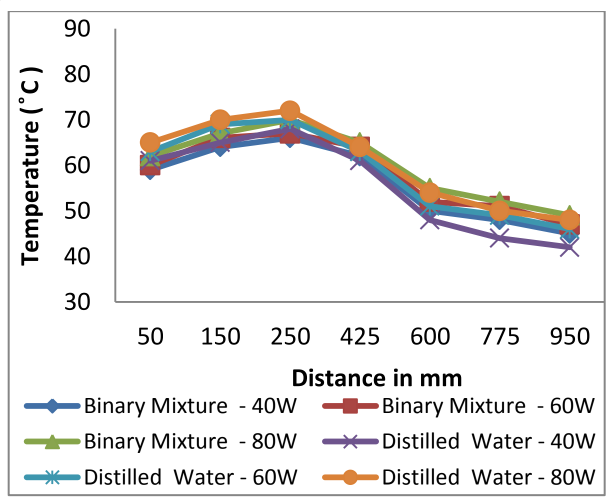

Fig.9: Flow rate 4Kg/hr and inclination 60°

International Journal of Engineering Research and General Science Volume 4, Issue 2, March-April, 2016
ISSN 2091-2730

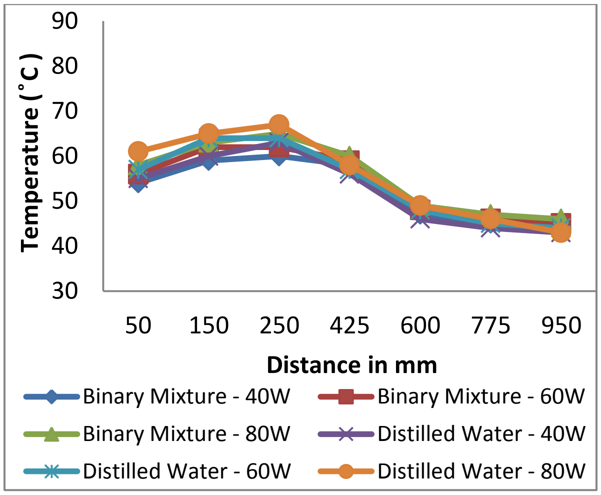

Fig.10: Flow rate 20Kg/hr and inclination 45°

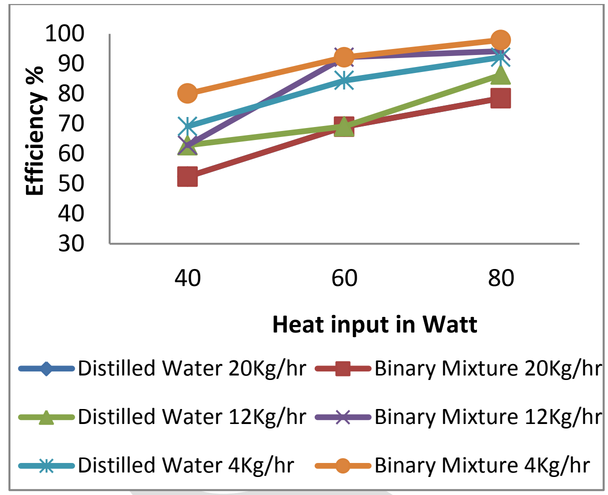

Fig.13: Efficiency for 90° inclination

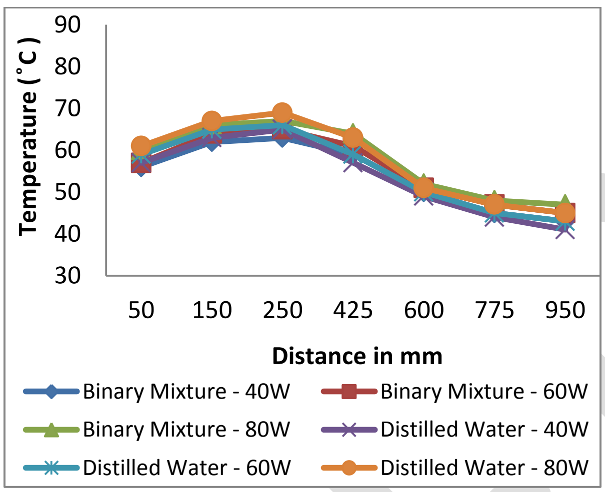

Fig.11: Flow rate 12Kg/hr and inclination 45°

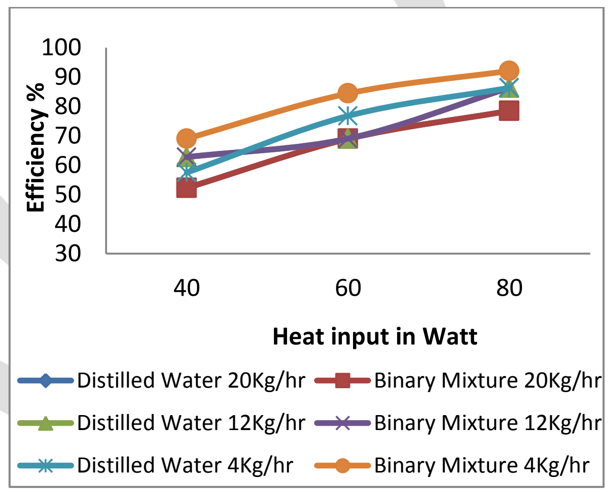

Fig.14: Efficiency for 60° inclination

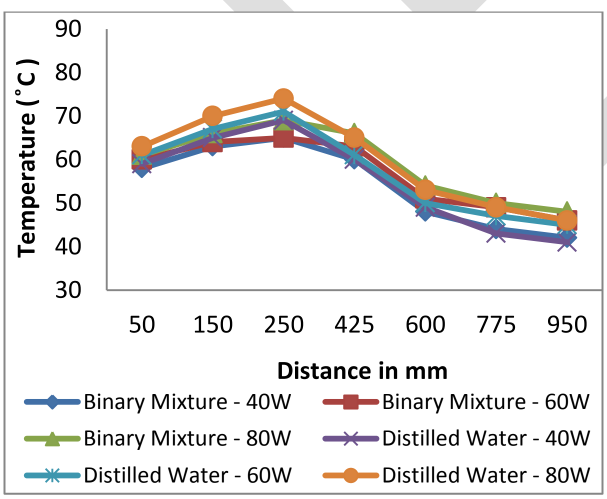

Fig.12: Flow rate 4Kg/hr and inclination 45°

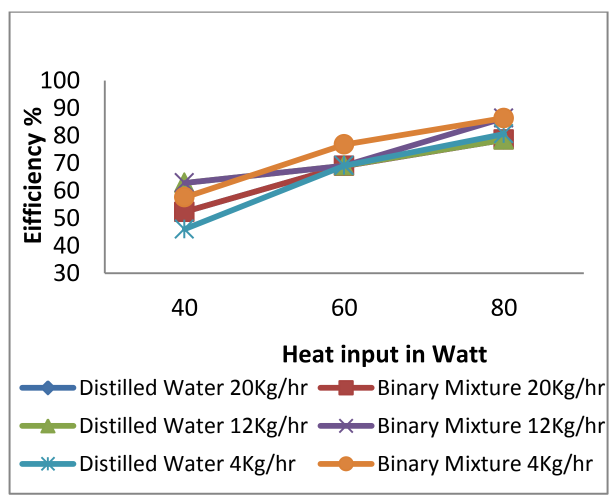

Fig.15: Efficiency for 45° inclination

VI. CONCLUSION

The experimental investigation was carried out on two phase closed thermosyphon charged with ethanol-methanol binary mixture and distilled water. The effect of inclination angle, coolant flow rate and heat load on the performance of thermosyphon was experimentally investigated. Coolant flow rate was varied from 4 kg/hr to 20 kg/hr along with inclination angle 40° to 90° with horizontal axis and heat load applied from 40 W to 80 W.

- Heat transfer efficiency is higher at coolant flow rate 4kg/hr. This is because at small cooling flow rate, coolant gets maximum time to exchange heat from condenser fluid and at larger cooling flow rate, that time span reduces because of high velocity. Therefore small flow rate coolant gets easily heated than larger one.
- Thermal performance of inclined thermosyphon with inclination angle 90° is better for coolant flow rate 4 kg/hr. This is because at vertical position condensate returns to evaporator at fast rate and there is restriction to appears flooding as well as entrainment limit.
- Based on the results, the thermosyphon charged with ethanol–methanol binary mixture has the maximum thermal performance than compared to thermosyphon charged with distilled water.

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