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Research Article

Effect of Mixture of Ethanol-Methanol as a Working Fluid on Heat Transfer Characteristics of Thermosyphon

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Abstract

Thermosyphons are wickless heat pipes and its importance towards cooling of high heat dissipating electronics and thermal industrial applications. The effect of mixture of ethanol-methanol as a binary working fluid on thermosyphon performance is being presented in this paper. The thermosyphon has main three components, an evaporator with a boiling increment structure, adiabatic section at the middle and condenser. Experiment has been done to assess the effects of binary fluid mixture and inclination on the performance of the thermosyphon. The selected thermosyphon has one inch (25.4) mm diameter and 500 mm length (have 200 mm evaporator, 100 mm adiabatic and 200 mm condenser section) designed to dissipate 120 watt heat from the application. The working fluid will be ethanol – methanol mixture in 50-50%, 60-40%, 70 -30 % like by volume and filled by 60% of evaporator section. The method tested by applying heat load to the thermosyphon by two band heater of 60 watt capacity as per application and the condenser section is cooled by water jacket with submerged water pump and flow control valve arrangement. The testing of the thermosyphon has done at inclination of 0°, 30° and 60° with respective vertical axis to study the effect on heat transfer ability of the system. It found the outcome from the experimental trial is that ethanol-methanol (60-40) % mixture proportion of binary fluid gives better performance of thermosyphon at angle inclination of 30°at 1.087E-05 kg/s of cooling water flow rate than other.

***Keywords**: Thermosyphon Performance, Binary Fluid, Mixture Proportion, Angle Inclination, Heat Transfer.*

1. Introduction

The thermosyphon is a wickless heat pipe works on gravity and has been proved as a heat transfer device with very high thermal conductance. In practical, its effective thermal conductivity exceeds 200 to 500 times that of copper. The amount of heat transfer by these devices is can be many times of magnitude more than pure conduction through a solid metal. They are low cost, very effective, and reliable heat transfer devices for applications in many thermal and waste heat recovery systems. Because of its satisfactory heat transfer effectiveness has its own importance in the low temperature difference heat transfer. A two-phase closed thermosyphon (TPCT) is a high performance heat transfer device and transfer the maximum amount of heat at a high rate with less temperature gradient. As it can transfer large amounts of heat over relatively large distances with minimum temperature differences between the heat source and heat sink it also referred as thermal super conductor. They are used in many applications like heat exchanger devices, in heat recovery applications, water heaters and solar energy systems and are showing some promise in high-performance, anti-freezing, baking ovens, electronics thermal management for situations which are orientation specific.

The TPCT is empty sealed tube which contains a small amount of working fluid (Phase Change Material). The evaporator section is exposing to band hater and heat conducted across the pipe wall so the liquid in the thermosyphon absorbs the applied heat and it converting to latent heat of vaporization. The vapour in the evaporator region is at a higher pressure than in the condenser section due to this the vapour to flow upward direction. In the condenser region, the vapour condenses thus releasing the latent heat of vaporization that was absorbed in the evaporator section.

Then heat exits through the tube wall and into water jacket. Within the tube, the flow of fluid is completed by the liquid flow due to gravity back to the evaporator section in the form of a thin liquid film. As it works on gravity to back liquid to the evaporator section, thermosyphon not be operating at inclinations close to the horizontal position. Following figure shows the working principal of two phase closed thermosyphon. It is oriented in the vertical position to understand its working principle.

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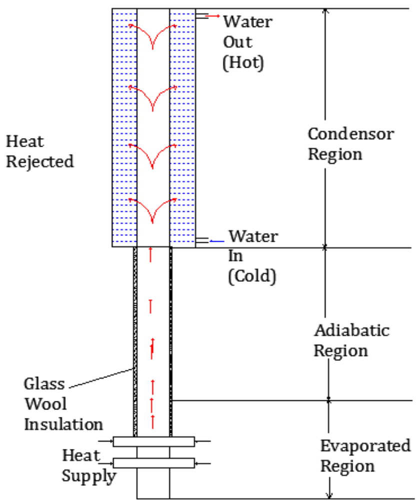

Fig. 1 Thermosyphon Working Principle

In this paper, the study of various categories research papers on the thermosyphon are studied. Research work includes its different input conditions of system i.e. filling ratio, aspect ratio and combination of various working fluids and angle inclination. The proposed work has been done mainly for effect of binary mixture proportions, angle inclination and cooling water flow rates. The purpose of following literature survey is to go through the main topics of interest i.e. effect of angle of inclination and mass flow rate of water for cooling process of condenser and binary mixture proportions of TPCT.

Different refrigerants used to determine the thermal performance of a two-phase thermosyphon in solar collector. Three identical small-scale solar water heating systems, using refrigerants R-134a, R407C, and R410A, were tested one by one under various environmental and load conditions. The performance of the system to check and investigated experimentally under clear-sky conditions with and without water load. The experimental results were compared to the results determined in the literature survey and they showed good agreement (Mehmet Esen, *et al.,* 2005).R11 Refrigerant is used as a base working fluid with the titanium nanoparticles of 21 nm diameter and copper heat pipe with the outer diameter 15 mm and length 600 mm. Effects of the charge amount of working fluid, heat pipe angle inclination on the efficiency of heat pipe are considered. For pure R11, at 60° angle inclination and 50% FR gives the maximum efficiency and with 0.1% nanoparticles concentration gives 1.40 times higher efficiency than that with pure refrigerant (Paisarn Naphon, *et al.*, 2009). Also it's the performance determine by charged with water and the dielectric heat transfer liquids FC-84, FC-77 and FC-3283 was experimentally investigated. The copper thermosyphon of 200 mm length, 6 mm ID, 40 mm evaporator length and 60 mm the condenser length was selected. With water as the working fluid 0.6 ml and 1.8 ml load of fluid consider, corresponding to approximate half-filled and overfilled evaporator. Liquid gives thermal performance up to 30–50W after which liquid entrainment compromised their performance (Hussam Jouhara, *et al.*, 2010).

Nanofluids (smaller than 100 nm) used for a two-phase closed thermosyphon (TPCT). Nanofluids of aqueous Al_2O_3 nanoparticles suspensions were prepared in various volume concentration of 1–3%. It seems from experimental results that when Al_2O_3/water nanofluid was used instead of pure water for different input powers, the efficiency of the thermosyphon increases up to 14.7% (S.H. Noie, *et al.,* 2009).Also, silver nanofluid used in it. The thermosyphon was made with copper material with 7.5, 11.1 and 25.4 mm ID. The filling ratios of 30%, 50% and 80% by evaporator length and aspect ratios of 5, 10, and 20 with an inclination angle 90°. The operating temperatures were 40°C, 50°C and 60°C. The research reports gives the effect of dimensionless parameters on heat-transfer characteristics and seems that FR has no effect on the ratio of heat-transfer characteristics in the vertical position, but working fluid properties affected the heat-transfer rate (T. Parametthanuwat, *et al.,* 2010).And iron oxide nanoparticles added to water used as a working fluid in thermosyphon. The tested concentration level of nanoparticles is 0%, 2%, and 5.3%. From results it seems that the addition of 5.3% (by volume) of iron oxide nanoparticles in water improved thermal performance compared with the operation with DI-water (Gabriela Huminic, *et al.*, 2011).

N_2–Ar binary mixture used into the cryogenic thermosyphon in different compositions, including pure N_2 and pure Ar. This binary mixture has wide operational temperature range of the cryogenic thermosyphon and it is about 64–150 K. Themosyphon is dry-out limit with Ar fraction below 0.503. The calculated results agree well with the experimental results (Z.Q. Long, *et al.,* 2013).It also charged with the ethanol-methanol binary mixture. Selected thermosyphon was copper tube of 1000 mm length with ID and OD of 24 mm and 26 mm respectively. Experiments were carried out on the inclination angle 40° to 90°, coolant flow rate 3.6 kg/h to 21.6 kg/h, heat load 25 W to 200 W. From result, maximum heat transfer efficiency is 86.39% which is higher at 3.6 kg/h coolant flow rate with 80° inclination angle and 190 W heat loads (N. A. Faddas, *et al.,* 2015).

Two-phase thermosyphons of length 2200 mm and OD 15.9 mm used in air to air heat exchangers with operating temperature ranges of -10 - 50 °C for the ambient (cold) side and 60-80 °C for the hot side. It seems from experiments a water-5% ethylene glycol mixture was used as suitable alternative, although under certain conditions its performance was less than that of R134a. It also saw that water gives the highest heat transfer rate, although it is not suited to the target temperature range, and methanol and R134anot perform well for most of the experimental range (Robert W. MacGregor, *et al.,* 2013).

Also, water used effectively in the experiments were conducted to evaluate the performance of a two phase closed loop thermosyphon. Finally, from the results show that the optimal fill charge ratio is between 7% and 10%, the cooling system has the optimal performance when control the condenser temperature of jacket water and flow rate at 5 °C and at 0.7 l/min respectively (A.A. Chehade*, et al.,* 2014).

Water-filled and 0.01 and 0.03 vol% graphene oxide (GO)/ water nanofluids-filled heat pipes with a screen mesh wick considerably study in order to investigate the effects of nanofluids on the heat pipe operation. The 0.01 vol% GO/water nanofluid-filled heat pipe showed better boiling heat transfer than 0.03 vol% GO/ water nanofluids due to the different structures of the deposited nanoparticle layers on the wicks (Kyung Mo Kim, *et al.,* 2016).

In thermo economic analysis study, understand experimentally effects of different three working fluids like methanol, petroleum ether and distilled water in the thermosyphon heat pipes which it heats the air is investigated. For various air velocities, an energy and an exergy efficiencies of the thermosyphon heat pipes investigated in terms of thermo economic concept. From thermo economic results of this study gives distilled water is more cost-effective than that of methanol and petroleum ether (Mustafa AliErsöz, *et al*., 2016).

From the above information, it observed that many researches is done on different kinds of working fluid solutions like refrigerants R-134a, R407C, R410A andR11and FC-84, FC-77 and FC-3283 etc., nanofluids such as Al_2O_3-water, silver nanofluid, iron oxide-water, graphene oxide (GO)/ water nanofluids etc., Binary mixtures like N_2-Ar, ethanol-methanol, water-5% ethylene glycol etc. and working fluids like methanol, petroleum ether and distilled water. In many investigation of thermosyphon it is observed that water gives better performance as a working fluid than other solutions. Due to its high boiling point it generally not used for cold temperature regions. By using other solutions as a working fluid does not get better thermal performance than water. So it time comes to use binary mixture of various solutions to get better thermodynamic property for using working fluid in two phase closed thermosyphon.

2. Experimental Setup

The experimental setup of two phase closed thermosyphon is illustrated in Fig.2. The main components of the set up are thermosyphon pipes, band heaters, cooling jacket with O-Ring, water tank, beaker, Frame for support and insulation provides to adiabatic section.

It consists of an empty closed copper tube having evaporator region at lower side, adiabatic region at middle and condenser region at the upper side. The total length of thermosyphon is 500 mm (having 200 mm evaporator, 100 mm adiabatic and 200 mm condenser region) with Diameter is 25.4 mm. The two Band Heaters with 60W capacity are attached to the evaporator and electrical supply to heater with 230V.

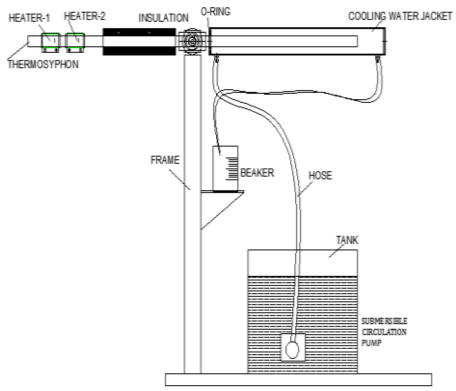

Fig. 2 Schematic Diagram of Experimental Setup

Ethanol-methanol binary mixture of different proportions like 50:50%, 60:40% and 70:30% is used with 60% filling of evaporation section. For adiabatic region glass wool is used as insulation material to prevent the heat loss. Condenser section is surrounded by concentric cylinder (water jacket) through which tap water flows. The hot water temperature from water jacket is measured by thermometer. The coolant flow is varied by a controlled valve and for flow circulation submerged pump is used with flow capacity 820 LPH. For initial evacuation of tube arrangement is made to attach vacuumed pump at the top and also to measure the pressure inside the tube, pressure gauge is attached. Evacuation is necessary to eliminate the effect of non-condensable gases. Following Table 1 shows the Design Parameters Table 2 shows the Performance Parameters of experimental setup which can be according to researcher's demand and interest.

Table 1 Design Parameter of Thermosyphon

Design Parameters	Description
Tube material	Copper
Tube diameter (mm)	25.4
Total length (mm)	500
Evaporator length (mm)	200
Condenser length (mm)	200
Adiabatic length (mm)	100

Table 2 Performance Parameter of Thermosyphon

Performance Parameters	Description
Working Fluid	Ethanol-Methanol Mixture
Filling Ratio (FR)	60%
Heat Input (Q)	120W
Insulation Material	Glass Wool
Aspect Ratio(L_e/D_i)	7.874
Angle Inclination(θ)	0°, 30° and 60° (wrt. Vertical)
Cooling Water Flow Rate (m_w)	$0.1869*10^{-5}$ kg/s to $4.6729*10^{-5}$ kg/s
Inlet Water Temperature (T_{wi})	Ambient (°C)

3. Experimental Analysis

3.1 Heat Transfer Rate

The following calculations were carried out to find the input and output heat transfer rate of the thermosyphon.
Heat Input to the evaporator section is given by equation

$$Q_{in} = V*I - Q_{loss}\ (W) \quad (1)$$

Where, Q_{loss} is the sum of heat losses from the evaporator section by radiation and free convection.

$$Q_{loss} = Q_{rad} + Q_{conv}(W) \quad (2)$$

The radiation heat transfer rate was calculated from Equation

$$Q = \varepsilon\ \sigma\ A_e\ (T_{we}^4 - T_{air}^4)(W) \quad (3)$$

And free convection heat transfer was calculated from Equation

$$Q = h_{conv}A_e\ (T_{ins} - T_{air})(W) \quad (4)$$

In this calculation we neglect the heat loss by evaporator section. So, neat heat supply is given by equation from equation

$$Q_{in} = V*I\ (W) \quad (5)$$

The heat transmitted from the condenser section is equal to the rejected heat to coolant water in the jacket, and was calculated from Equation

$$Q_{out} = m_w.\ C_{pw}\ (T_{wo}-T_{wi})\ (W) \quad (6)$$

3.2 Mass Flow Rate of Coolant

Following table shows various readings of mass flow rates of coolant for calculation

Table 3 Mass Flow Rate of Water

Sr. No.	Volume of Water, V_w (m^3)	Time, t (s)	m_w(kg/s) *10^{-5}
1	0.0002	4.28	4.6729
2	0.0002	4.83	4.6189
3	0.0002	4.98	4.0161
4	0.0002	6.4	3.125
5	0.0002	10	2
6	0.0002	18.4	1.087
7	0.0002	55.8	0.3584
8	0.0002	107	0.1869

The mass flow rate of coolant varies from 0.1869*10^{-5} kg/s to 4.6729*10^{-5} kg/s. And is calculated by following equation

$$m_w = \frac{V_w}{t} * \rho_w\ (\text{Kg/s}) \quad (7)$$

Where, Density of water is taken as 1000 Kg/m^3 and Specific heat of water is taken as 4.184 * 10^3 J/KgK.

3.3 Binary Working Fluid

Selection of working fluid for thermosyphon is concerned; first go through the various thermodynamic properties of ethanol and methanol. It showed below in the Table 4(N. A. Faddas, *et al.,* 2015).

In this experiment, it used various ethanol-methanol ratios e.g. 60:40 (by volume); at this ratio these two solutions are completely soluble with each other. . It showed below in the Table 5(N. A. Faddas, *et al.,* 2015).

Table 4 Properties of Ethanol and Methanol

Properties	Methanol (CH_3OH)	Ethanol (C_2H_5OH)
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

Table 5 Properties of Ethanol- Methanol Mixture

Properties	Ethanol-Methanol
Boiling point (°C)	72.8
Melting point (°C)	-125.6
Useful temperature range (°C)	0 to 100
Thermal conductivity at 300 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°C to 100°C temperature applications. Hence ethanol-methanol mixture was selected for the experimental assessment of the thermosyphon as a working fluid (N. A. Faddas, *et al.,* 2015).

4. Results and Discussions

The quantity of heat transfer to the coolant water can be calculated from inlet and outlet water temperature difference and by considering water mass flow rate and specific heat. So we will see the graphs of temperature difference and mass flow rate of water. Following graphs shows the relation between mass flow rates (m_w) Vs temperature difference ($T_{wo}-T_{wi}$) at various angle inclinations (θ).

From figures, it shows that as the mass flow rate of water increases, the temperature difference increases up to a certain limit then further it decreases with the increase in mass flow rate of water.

Different colors are used to indicate difference mixture proportions in the graphs show in the figures. Blue color indicates the Ethanol-methanol mixture (50:50) % ratio by volume, Red color shows (60:40) % ratio by volume and Green color shows the (70:30) % ratio by volume.

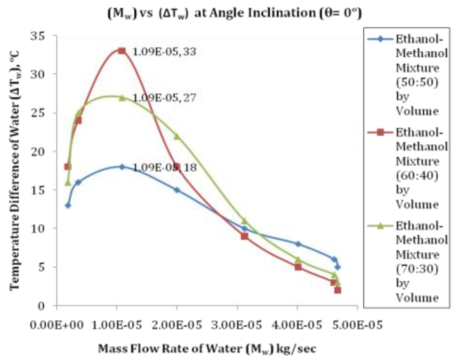

Fig. 3 Mass Flow Rate of Water Vs Temperature Difference of Water at θ = 0°C.

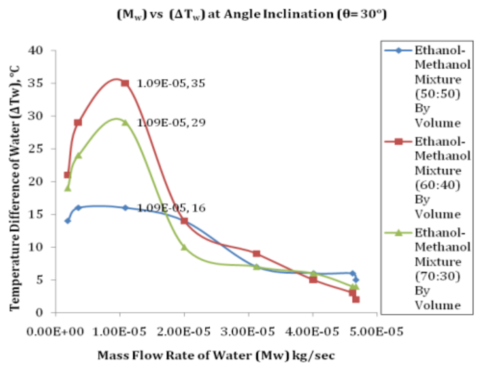

Fig. 4 Mass Flow Rate of Water Vs Temperature Difference of Water at θ = 30°C.

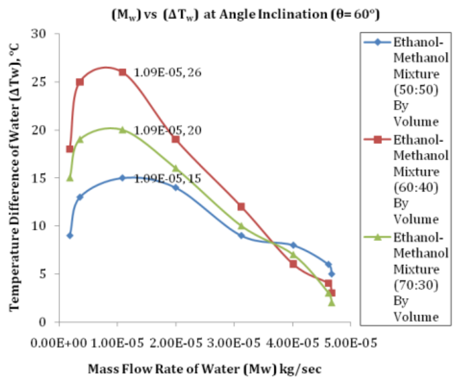

Fig. 5 Mass Flow Rate of Water Vs Temperature Difference of Water at θ = 60°C.

The graphs show the performance of mixture by water temperature difference as heat rejected be mixture is equal to heat absorbed by cooler fluid. At 0° inclination (vertical thermosyphon), we get more temperature difference of water for (60:40) % proportion mixture as that of other two. The temperature difference by (70:30) % mixture is more as that of (50:50) % and less that of (60:40) %. The temperature difference of water by red line is 33°C, by green line is 27°C and blue line show lower temperature difference it is about 18°C. For 1.09E-05 kg/s mass flow rate we get maximum temperature difference as that of others, we get minimum temperature difference at maximum mass flow rate of 4.67E-05 kg/s. If we observed three angle inclination cases, we come to know that we get maximum temperature difference of water at 30° inclination that of 0° and 60° and it is about 35°C. And thermosyphon output (Q_{out}) is proportional to temperature difference of water (T_{wo}–T_{wi}). So we get the best performance of thermosyphon for (60:40) % mixture at 30° inclination and 1.09E-05 kg/s mass flow rate.

Conclusions

1) Thermosyphon has satisfactory heat transfer effectiveness so has its own importance in the low temperature difference heat transfer and its effectiveness is depends on the phase change working fluid.
2) Different working fluids used in various thermosyphons according to its application in various areas. In this experiment ethanol-methanol binary mixture can be used stationary electronic devices, oil cooling of stationary engine. Also very few research is done on ethanol-methanol mixture as that of other binary fluids.
3) The binary mixture (60:40) % by volume gives the best result as that of (50:50) % and (70:30) % by volume mixtures.
4) From this experiments, it come to know that maximum temperature difference of water at 30° inclination that of 0° and 60° and it is about 35°C. And thermosyphon output (Q_{out}) is proportional to temperature difference of water (T_{wo} – T_{wi}). So we get the best performance of thermosyphon for (60:40) % mixture at 30° inclination and 1.09E-05 kg/s mass flow rate.

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