PERFORMANCE INVESTIGATION OF INCLINED TWO PHASE CLOSED THERMOSYPHON BY USING BINARY MIXTURE

[1]Vikram D. Ghadage, [2]Sachin V. Mutalikdesai
[1]PG Student, [2]Assistant Professor
[1]Department of Mechanical Engineering
[1]Trinity College of Engineering and Research, Pune, India

Abstract*—Thermosyphons are hollow sealed weak less heat pipes and its crucial role towards cooling of highly heat dissipating electronics and industrial thermal application. The effect of binary mixture as a working fluid on performance of inclined two phase closed thermo syphon will investigate in this paper. The thermo syphon has three principle components; condenser is at top, adiabatic at middle section and an evaporator at bottom section. Investigation has been done to assess the effects of binary mixture fluid proportion on inclined thermoyphon. The thermosyphon selected has 25.4 mm (1 inch) diameter and length of 500 mm (have 200 mm condenser, 100 mm an adiabatic and 200 mm evaporator section) designed to the 240 watt heat dissipation from the application. The ethanol methanol mixture proportion (like 50-50%, 60-40% and 70-30 % by volume) is working fluid with filling 60% of evaporator section. The investigation is done by applying the heat load to the thermosyphon using four band heater of each 60 watt capacity and water as coolant flowing through condenser jacket to cool condenser by pump and flow control arrangement. The investigation of inclined thermosyphon has done at inclination of 90°, 75°, 60°, 45°, 30° and 15° with reference to horizontal axis to study the effect on heat transfer performance of the system. The Properties of Ethanol Methanol Mixtures studied at various proportions and find out maximum heat input for various mixtures by heat transfer limitations correlations. So, heat input of 240 W is supply to 60% filling of evaporator region. 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 45° at 0.001667 kg/s of cooling water flow rate than other. Efficiency of pipe for (60:40) mixture is 23.26 % while (70:30) shows less 20.35 % and (50:50) gives lower 17.44 % at 45° inclination and 0.001667 kg/s mass flow rate. Also it come to know that (50:50) and (70:30) mixture proportions gives better performance at 60° and 90° that of other angle inclinations.

***Index Terms*—Binary Fluid, Mixture Proportions, Angle Inclination, Thermosyphon Performance, Heat Transfer.**

I. INTRODUCTION

The thermosyphon is a hollow wickless heat pipe works on gravity principle and has proved as a heat transfer device with high thermal conductance. In practical, the effective thermal conductivity of thermosyphon is more 200 to 500 times that of copper material. Therate of heat transfer by these devices can be many times in magnitude than pure conduction through a solid metal. They are very effective, have low cost, and more reliable heat transfer devices for applications in many waste heat recovery systems and industrial thermal applications. Because of its satisfaction heat transfer effectiveness has its own crucial role in the low temperature difference heat transfer. A two-phase closed thermosyphon (TPCT) is a device which transfers heat with high rate at low temperature gradient. It also known as thermal super conductor as it can transfer large amounts of heat over relatively large distances with less temperature differences between the heat source and sink. Its main applications in water heaters, solar systems, heat recovery and are shows some promised in high-performance. [1]. A modern electronic devices used in high speed and high level of heat generation have to be small in size as well as light in weight. So, the reliability and level of heat dissipation efficiency largely required for these devices. Heat Pipe and/or thermosyphon technology has been used in a many applications in the heat transfer devices. Generally, the coolants used in the heat transfer devices study are air, water, and fluoro-chemicals. Hence, the heat transfer ability can limited by the working fluid transportation properties [4]. Effective thermal management being a crucial role in many modern and advanced technologies due to constant demands of faster speeds and continuous reduction of equipment's dimensions. Recent modern technological changes in manufacturing results in the miniaturization of many devices with various applications. So for effective heat dissipation from the small size components thermosyphon plays an important role [5]. It is observed that water gives better performance as a working fluid than other solutions in many investigation of thermosyphon. Because of its high boiling point it generally not used for cold temperature regions. From investigation sometimes it seems that by using other solutions as a working fluid does not get better thermal performance than water. So it is very necessary to use binary mixture of various working fluids to get better thermodynamic property in two phase closed thermosyphon [2]. In this paper, ethanol-methanol mixture of various proportions of binary fluid with 60% filling of evaporator is used. With these various proportions of mixture thermosyphon performance can be assessing at various angle inclinations of pipe.

Following Fig. 1 shows the working principal of simple empty sealed two phase closed thermosyphon. It is shows in the vertical position for understanding its working principle. It is hollow thermal pipe have some thickness which contains a small amount of working fluid as Phase Change Material. The evaporator section is contact with 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 due to working fluid properties. So working fluid pressure increases and high pressure vapor flow to upward direction. At the middle adiabatic region, insulation is fitted so that no heat transfers to surrounding. In the condenser region, the water is circulated around it as shown in the Fig. 1 which absorbs the latent heat of working fluid into the water jacket. Then vapor condenses thus releasing the latent heat that was absorbed in the evaporator section. Then the working fluid is flow due to gravity back to the evaporator section in the form of a thin liquid film.

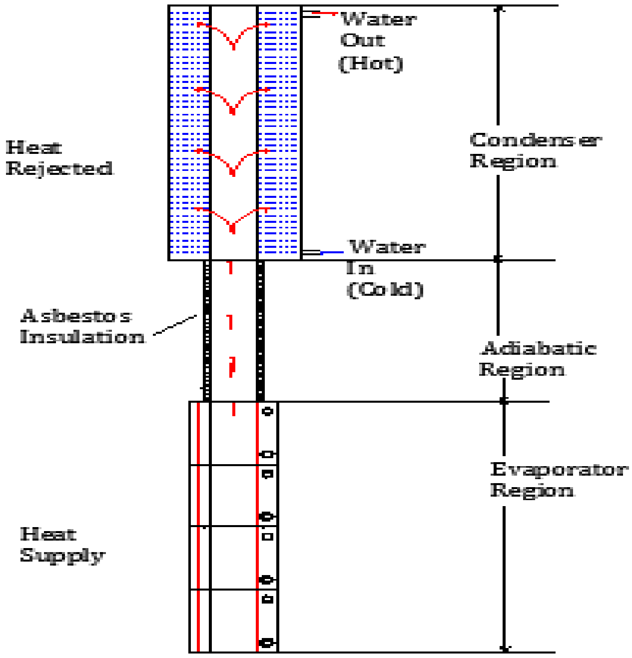


Figure 1Thermosyphon Working Principle

As it works on gravity to back liquid to the evaporator section, thermosyphon not be operating at inclinations close to the horizontal position. The working fluid, fill ratio, heat input is main parameters of the performance of thermosyphon and it can be assessed with dimensional less numbers.

II. EXPERIMENTAL SET UP AND DATA ANALYSIS

Experimental setup of inclined two phase closed thermosyphon is illustrated in Fig. 2.

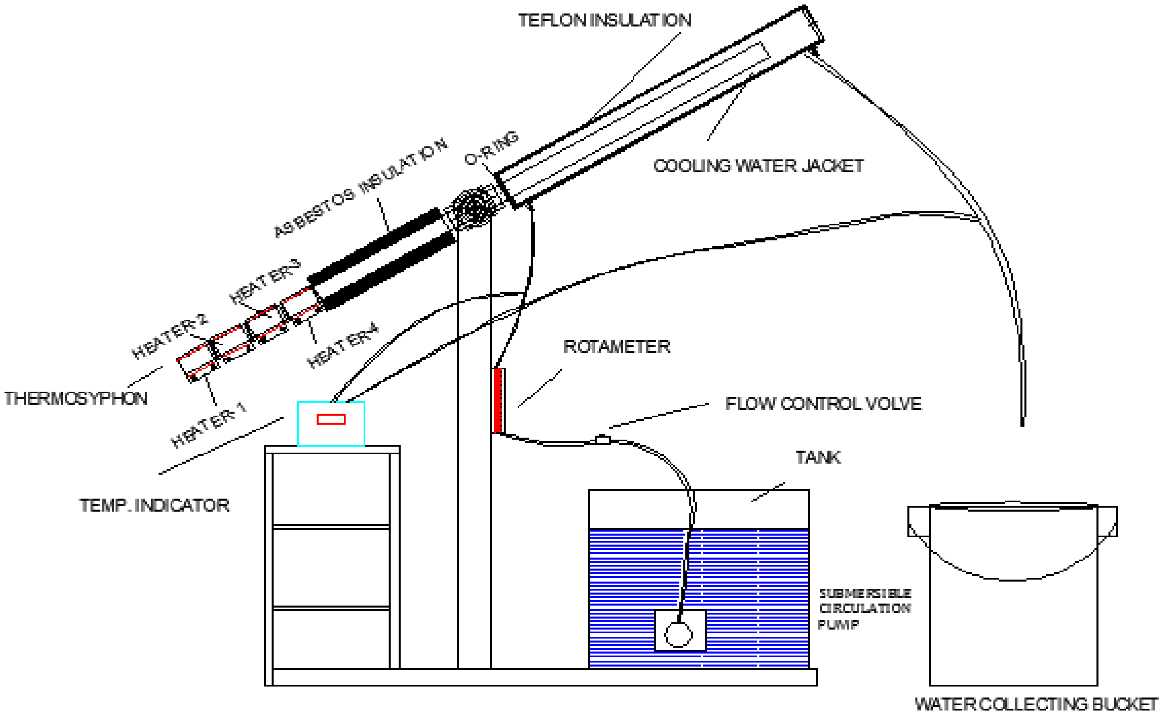


Figure 2 Schematic Diagram of Experimental Set-Up

It consists of an enclosed evacuated copper tube having evaporator section at lower side, adiabatic section at middle and condenser section at the upper side. Coil heaters or four band heaters of 60W each are attached to the evaporator section for heat supply. At the middle of the pipe asbestos is used as insulation material for preventing heat loss pipe act as an adiabatic section also at inside of the holder Bakelite is used as insulating material. Condenser section is surrounded by concentric cylinder through which water flows at the rate of 820 LPH by the submersible pump. Condenser water jacket is covered by Teflon insulation to prevent heat loss it can be prevent the temperature up to 300°C. The coolant flow is varied by a controlled valve. Vertical dead weight rotameter is attached to frame for measurement of rate of flow. 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.

(a) Properties of working fluid

Working fluid plays an important role on performance of thermosyphon so selection of working fluid for thermosyphon is concerned; first go through the various thermodynamic properties of ethanol and methanol. The thermo- physical properties of ethanol and methanol at atmospheric pressure and room temperature are showed below in the Table 1.

Table 1Properties of Ethanol and Methanol [2, 8 and 9]

Properties	**Methanol (CH_3OH)**	**Ethanol (C_2H_5OH)**
Boiling point (°C)	65	78
Melting point (°C)	-98	-144
Useful temperature range (°C)	10 to 130	0 to 130
Thermal Conductivity at 300K (λ), (W/m-K)	0.202	0.171
Latent heat of vaporization (h_{fg}), (kJ/kg)	1101	846
Surface Tension (σ), (N/m)	$22.6* 10^3$	$22.8* 10^3$
Dynamic Viscosity (μ), (Ns/m^2)	$0.60* 10^6$	$1.15* 10^6$
Density of Liquid (ρ_l), (kg/m^3)	750.8	758.1
Density of Vapor (ρ_v), (kg/m^3)	0.566	1.372

In this experiment binary fluid mixture of various proportions (50:50), (60:40) and (70:30) (by volume) are charged; at this proportions these two solutions are completely soluble with each other. The properties are finding at various mixture proportions. So properties of these mixtures at Atmospheric Pressure are showed in the Table 2.

Table 2 Properties of Ethanol-Methanol Mixtures

Mixture Proportion	**B.P.**	**M.P.**	**λ (W/m-K)**	**h_{fg} (kJ/kg)**	**σ $*10^3$ (N/m)**	**μ* 10^6 (Ns/m^2)**	**ρ_l (kg/m^3)**	**ρ_v (kg/m^3)**
50:50	71.5	-121	0.1865	973.5	22.70	0.875	754.45	0.969
60:40	72.8	-125.6	0.1834	947.6	22.72	0.930	755.18	1.0496
70:30	74.1	-130.2	0.1803	922.5	22.74	0.985	755.91	1.1302

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. These properties of various proportions are helpful to find out the maximum heat input supply to evaporator region to prevent the heat transfer limitations and to run thermosyphon effectively in safe mode.

(b) Heat transfer Limitations Governing Equations for Maximum Heat Input

Although thermosyphons are very efficient and reliable heat transfer devices, there are some parameters that put limitations and constraints on the steady and transient operation of thermosyphon. These limitations determine the maximum heat transfer rate, which must be examined for each working fluid. Physical phenomena that might limit heat transport in two-phase closed thermosyphons are due to flooding, dry-out, and boiling. From heat transfer limitations correlations, find out the flooding limit, boiling limit and Dry-out limit for various mixtures. The minimum flooding limit for the (70:30) mixture proportion of ethanol methanol is 431 W. Since for this paper the selected input heat (240 W) is lower than all of these limits, it can be said that the thermosyphon was operated in the safe situation. The determined heat transfer limitation ranges for this thermosyphon for FR 60% of various mixtures by volumes are illustrated in Table 3

Table 3 Maximum Heat Input for Heat Transfer limit at 60% FR

Heat Transfer Limitations	**Maximum Heat Input (W)**		
	(50:50)	**(60:40)**	**(70:30)**
Flooding Limit	1178	432	431
Boiling Limit	2301	536	534.8
Dry-out Limit	27696	24511	24490

III. RESULTS AND DISCUSSIONS

The Performance of thermosyphon is ratio of heat output carried by water (Q_{out}) at condenser section to heat input by band heater (Q_{in}) at evaporator section as shown in Fig. 2

Mathematically it is given by

$$\eta = \frac{Q_{out}}{Q_{in}} \quad (1)$$

The various mixture proportions of Ethanol Methanol Mixtures like (50:50), (60:40) and (70:30) by volume are assessed in thermosyphon at different angle inclinations of pipe. Constant heat input of 240 W is given to evaporator of 60 % FR. The heat transfer from condenser region of pipe to the coolant water can be calculated by inlet and outlet water temperature difference (ΔT_w) °C and by considering water mass flow rate (m_w) in kg/s and specific heat (C_{pw}) J/kgK. The pipe is fitted in the set up shown in Fig. 2 at vertical position (θ = 90°) and the performance of pipe is checked by various mixture proportion of binary fluid.

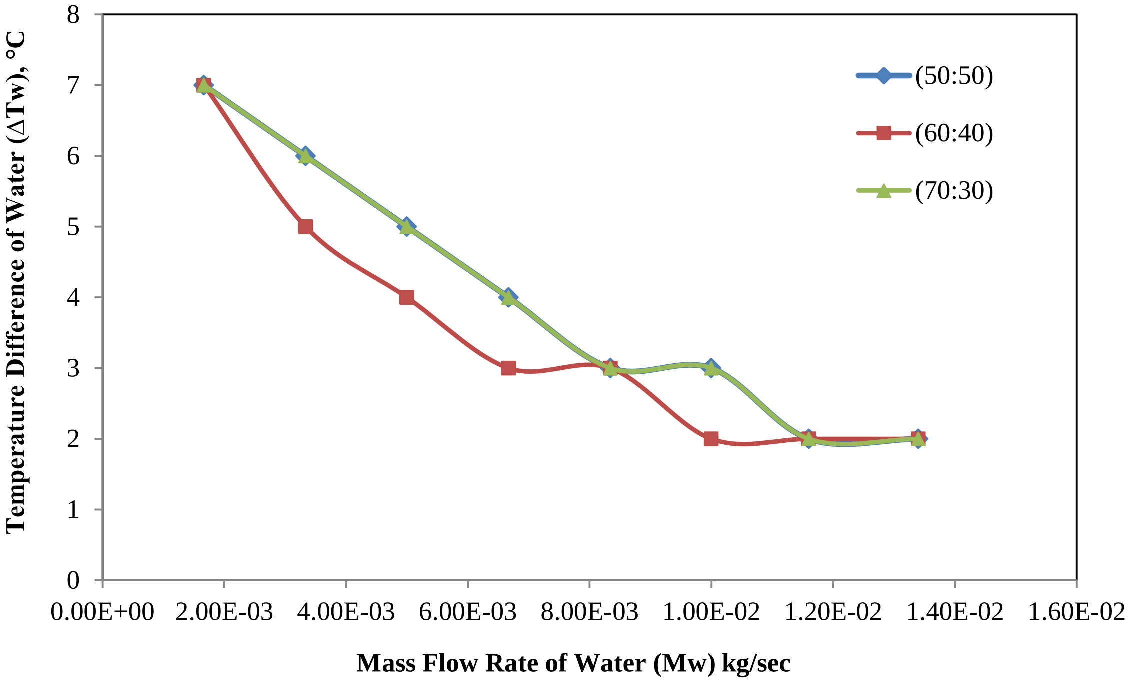


Figure 3 Mass Flow Rate Vs Temperature Difference at 90°

From Fig. 3 it comes to know that pipe gives maximum temperature difference about 7°C at 0.001667 kg/s in vertical position. Pipe gives minimum temperature difference at mass flow rate of 0.0134 kg/s. The mass flow rate from 0.01 kg/s to 0.0134 kg/s shows almost same temperature difference. At 90° angle inclination, (50:50) and (70:30) mixture gives the same behavior at all mass flow rates. (60:40) mixture gives the different behavior that of other two mixtures. It gives less temperature difference that of other two mixture fluids. The (50:50) and (70:30) mixture gives optimum temperature that of (60:40) mixture for vertical position. At 75° angle inclination, (50:50) and (70:30) mixture proportion gives the same behavior at initially less mass flow rates showed in Fig. 4.

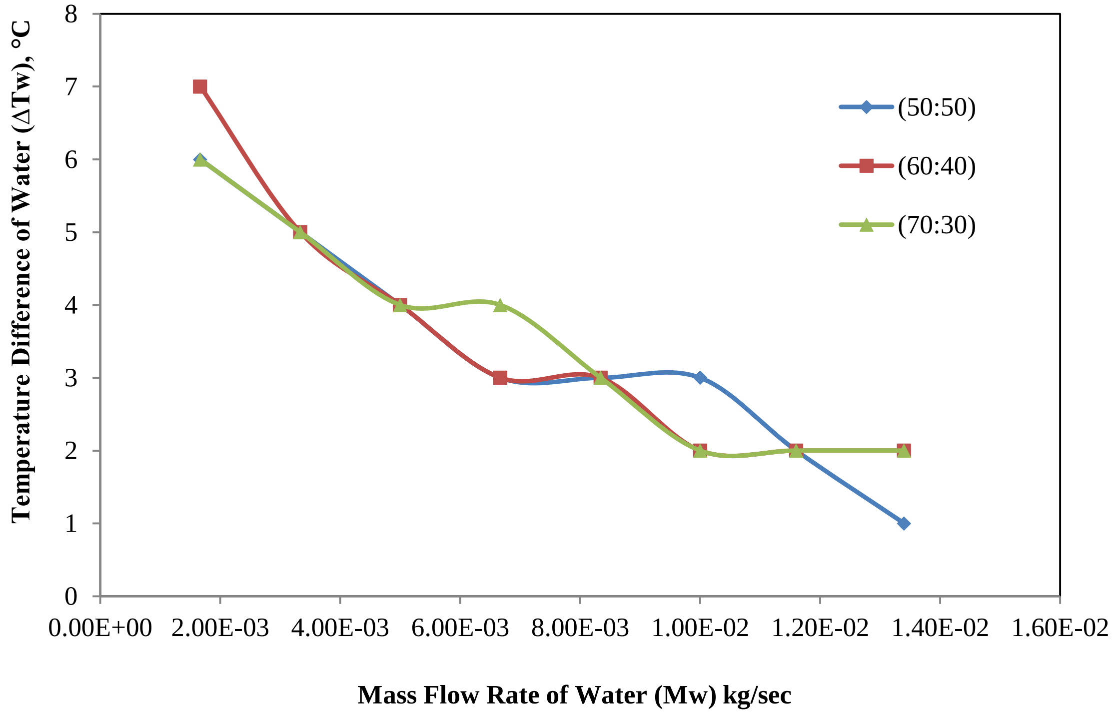
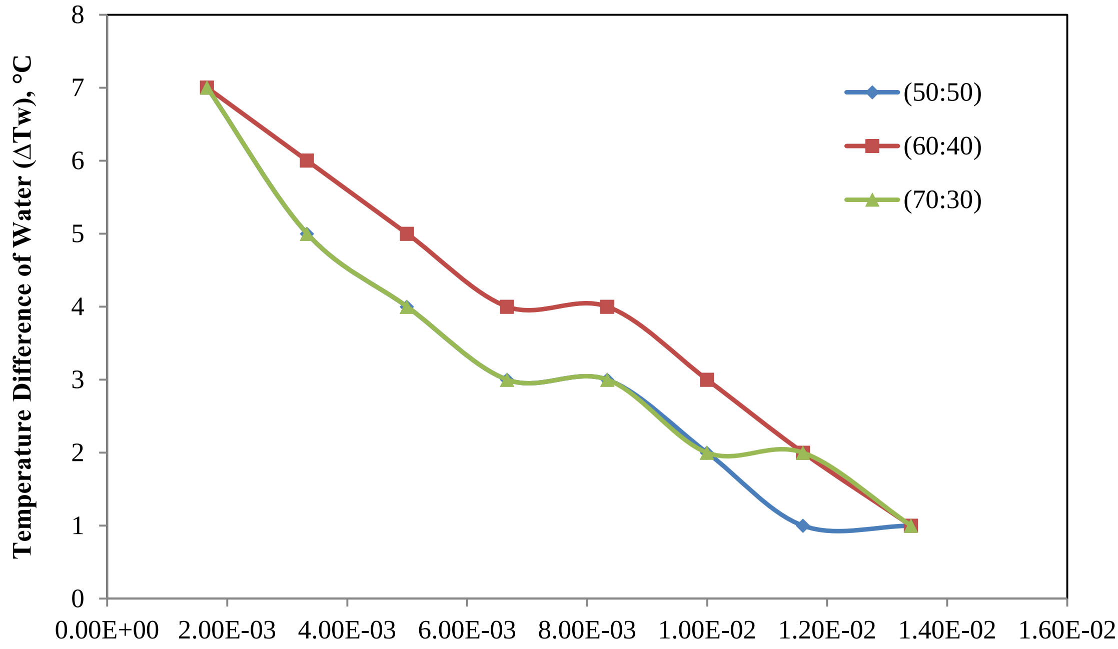


Figure 4 Mass Flow Rate Vs Temperature Difference at 75°

At 60°, the temperature difference of water is increases about 7° C shown in Fig. 5. For 60° angle inclination the (60:40) mixture gives maximum temperature difference as compared to other two mixtures. The (50:50) and (70:30) mixtures shows same behavior that of (60:40) mixtures. The Fig. 5 shows the behavior of mixture at 60° and it also conclude that as angle deviates from vertical position to inclined position the (60:40) gives better temperature difference. It deviates slightly more that of other two mixtures.

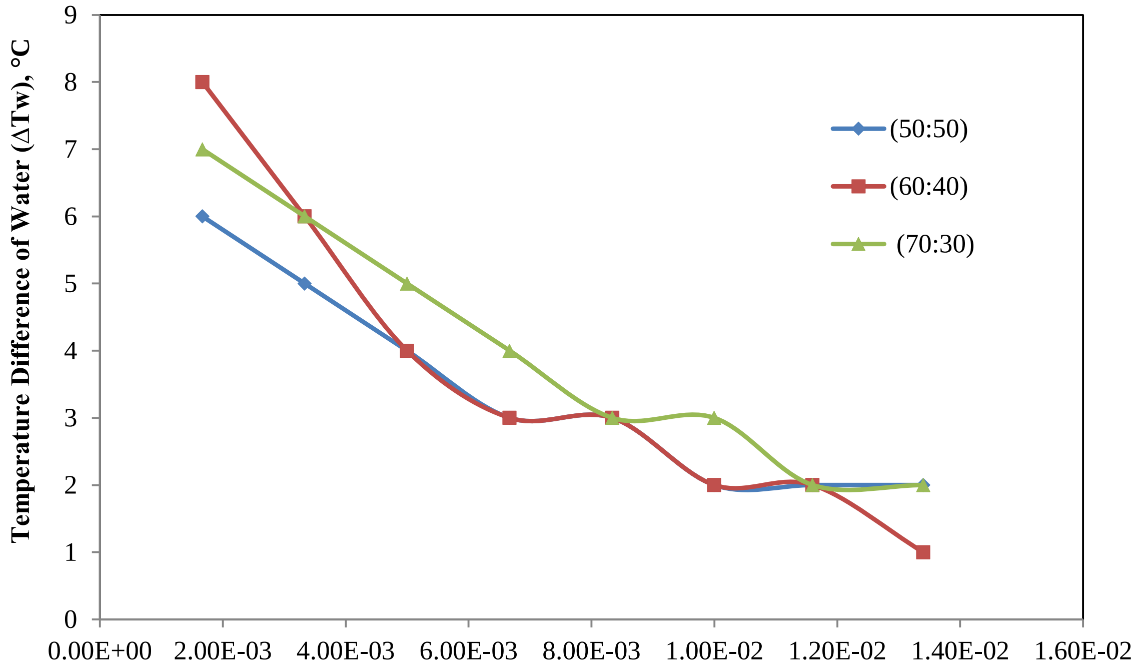


Mass Flow Rate of Water (Mw) kg/sec

Figure 5 Mass Flow Rate Vs Temperature Difference at 60°

Up to mass flow rate 0.01 kg/s the (50:50) and (70:30) mixtures shows same behavior above that as mass flow increased (70:30) increased more temperature as that of (50:50) mixture shown in the Fig. 5.

As inclined the pipe from 60° to 45° the performance of (60:40) mixture increased and it gives maximum temperature difference that of other angle inclination shown in Fig. 6. It can be seen that about 8°C temperature difference of water is achieved for (60:40) mixture at inclination and mass flow rate of0.001667 kg/s while other mixture at same mass flow rate gives 6°C and 5°C.As mass flow rate of water increased further it gives sudden fall of temperature that of other mixture. Fig. 6 indicates the behavior of pipe by using different mixture of working fluid at 45° inclination.



Mass Flow Rate of Water (Mw) kg/sec

Figure 6 Mass Flow Rate Vs Temperature Difference at 45°

Now as the pipe inclined toward horizontal axis from 45° to 30° the temperature of various mixture proportions decreases by 1°C and it is 7°C and 6°C respectively. Fig. 7 shows the performance of (60:40) and (70:30) mixture decrease while the performance of (50:50) remains same there is no change in temperature difference as of previous case. The (50:50) and (70:30) mixture gives same temperature difference at all mass flow rates while (60:40) mixture deviates from these mixtures at 0.001667 kg/s and at 0.01 kg/s. Also performance same for all mixtures at 0.0116 kg/s to 0.0134 kg/s and it is about 2°C.

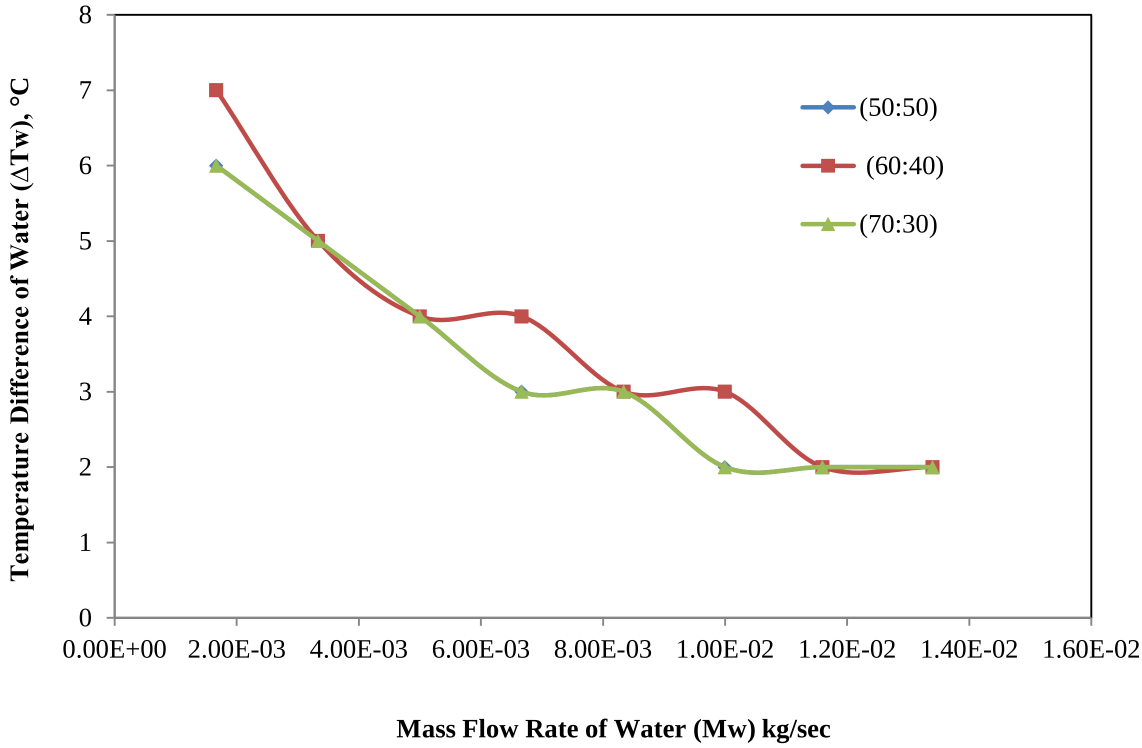


Figure 7 Mass Flow Rate Vs Temperature Difference at 30°

Then the pipe is rotate to horizontal at 15° in this angle inclination the temperature shown (60:40) mixture and (50:50) mixture shows same temperatures at all mass flow rates shown in Fig. 8. All mixture gives less performance at angle inclination of 15°. At initial value of mass flow rate and final value of mass flow rate of mixture all mixture behaves same but at middle of mass flow rate between 0.003334 kg/s to 0.008334 kg/s (70:30) mixture gives better performance that of other two mixture proportions shown in Fig. 8.

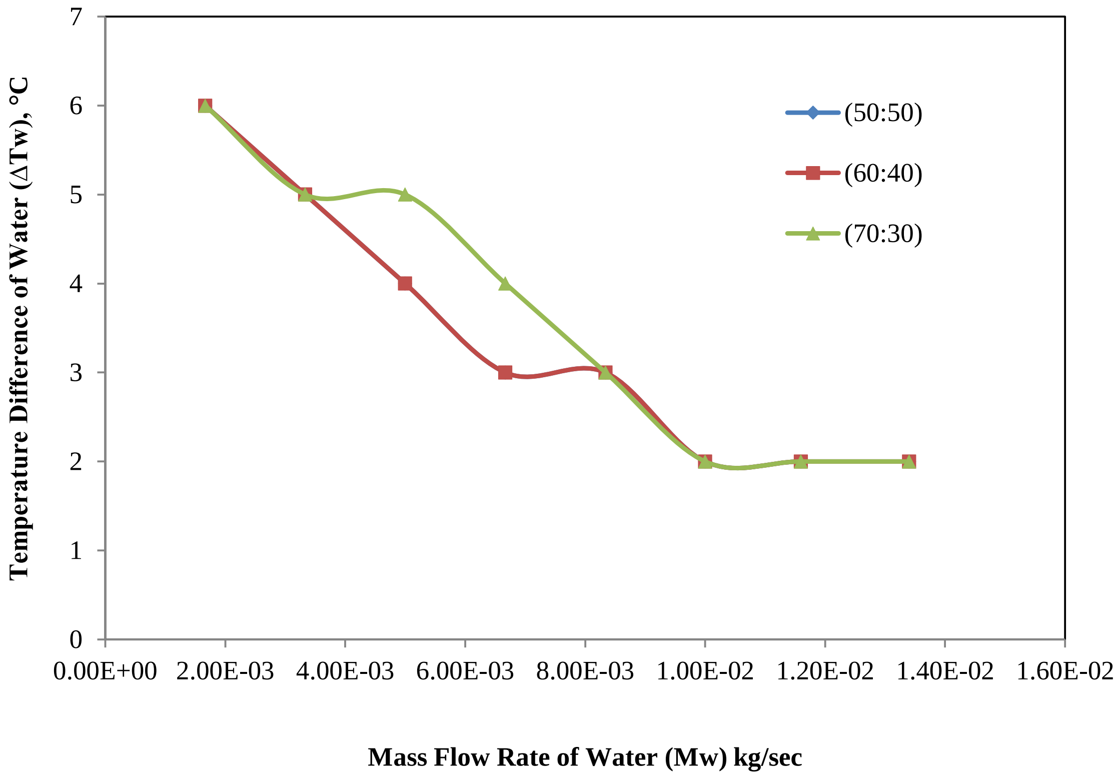


Figure 8 Mass Flow Rate Vs Temperature Difference at 15°

The performance of pipe is ratio of heat output of water at condenser to heat input at evaporator section. So, performance of pipe is directly proportional to heat output. Fig. 9 shows the graph of efficiency of pipe Vs angle inclination at optimum mass flow rate of 0.001667 kg/s for various mixtures.

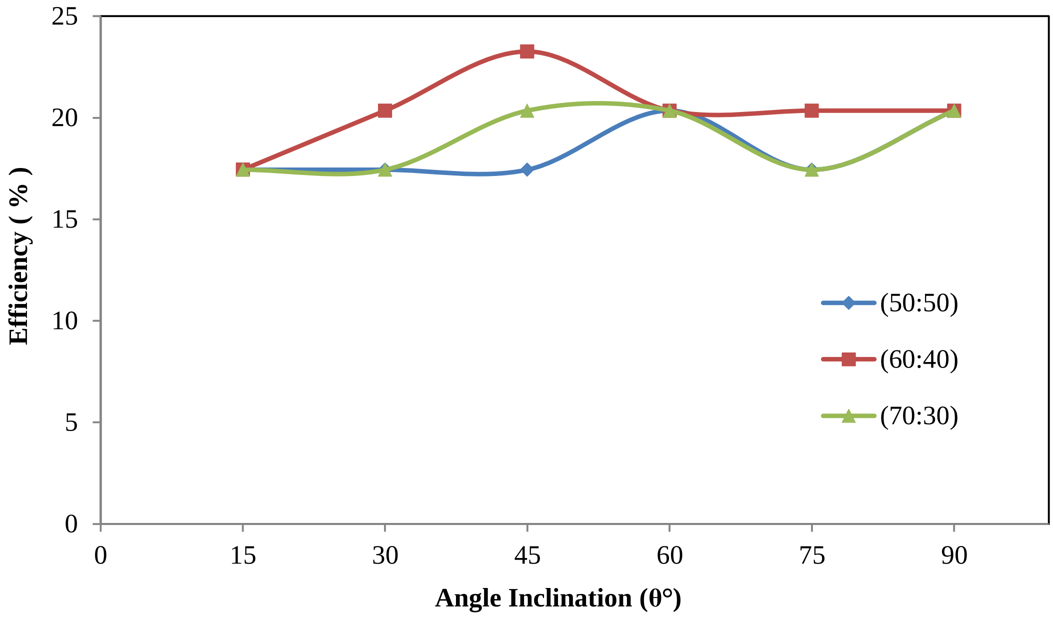


Figure 9 Efficiency Vs Angle Inclination at Optimum Mass Flow Rate

In Fig. 9, thermosyphon pipe gives the optimum performance for (60:40) mixture proportion of ethanol methanol mixture at 45° angle inclination. It is about 23.26 % for (60:40) mixture while (70:30) mixture shows less 20.35 % and (50:50) gives 17.44 % lowest. From Fig. 9 it also stated that efficiency of different mixtures increase as angle increases form horizontal up to 45° then it decreases as further angle increased up to 90°. Thermosyphon pipe gives maximum performance for (60:40) mixture that of (70:30) mixture and (50:50) mixture at 45°angle inclination and 0.001667 kg/s of mass flow rate of water.

IV. CONCLUSIONS

The aim of proposed work is focused on performance analysis of thermosyphon system by adopting the different proportions of ethanol-methanol binary mixture. For this purpose the performance analysis of the TPCT by considering the angle inclinations of pipe and mass flow rate of water, and their effects on it are experimentally calculated and theoretically studied and the results are presented as follows.

1) The Properties of Ethanol Methanol are studied at various proportions of Mixtures and find out maximum heat input for various mixtures by heat transfer limitations correlations. So, heat input of 240 W is supply to evaporator region of 60 % FR.
2) Performance of thermosyphon analyzed by various mixture proportions at various angle inclinations of pipe and mass flow rate of water at condenser section. Pipe gives the high performance for (60:40) mixture proportion of ethanol methanol mixture that of other mixture proportions at 45°.
3) As angle of inclination increases from horizontal efficiency of thermosyphon increases up to 45° inclination then decrease up to 75° and then increased up to 90°.
4) Efficiency of pipe for (60:40) mixture is 23.26 % while (70:30) mixture shows less 20.35 % and (50:50) mixture gives lower 17.44 % at 45° inclination and 0.001667 kg/s mass flow rate.
5) Also it come to know that (50:50) and (70:30) mixture proportions gives better performance at 60° and 90° that of other angle inclinations.

REFERENCES

[1] A.B. Gadge, N.S. Gohel, "Effect of Heat Transfer in Circular Heat Pipe with Ethanol Methanol and Al2O3 as a Nano fluid". International Journal of Science & Techno ledge, Vol. 2, Issue 5, pp. 397-402, 2014.

[2] N. A. Faddas, K. V. Mali, "Thermal Performance of Thermosyphon Heat Pipe Charged with Binary Mixture", International Journal of Science, Engineering and Technology Research, Vol.4, pp. 92-102, 2015.

[3] T. Parametthanuwat, S. Rittidech, A. Pattiya, "A correlation to predict heat-transfer rates of a two-phase closed thermosyphon (TPCT) using silver nano fluid at normal operating conditions", International Journal of Heat and Mass Transfer, Vol. 53, pp. 4960-4965, 2010.

[4] Paisarn Naphon, Dithapong Thongkum, Pichai Assadamongkol, "Heat pipe efficiency enhancement with refrigerant nanoparticles mixtures", Energy Conversion and Management, Vol. 50, pp. 772-776, 2009.

[5] S.H. Noie, S. ZeinaliHeris, M. Kahani, S.M. Nowee, "Heat transfer enhancement using Al2O3/water nanofluid in a two phase closed thermosyphon", International Journal of Heat and Fluid Flow, Vol. 30, pp. 700-705, 2009.

[6] HussamJouhara, Anthony J. Robinson, "Experimental investigation of small diameter two-phase closed thermosyphons charged with water, FC-84, FC-77 and FC-3283", Applied Thermal Engineering, Vol. 30, pp. 201-211, 2010.

[7] Robert W. MacGregor, Peter A. Kewc, David A. Reay, Investigation of low Global Warming Potential working fluids for a closed two-phase thermosyphon, Applied Thermal Engineering, Vol. 51, pp. 917- 925, 2013.

[8] Matthias H. Buschmann, "Nano fluids in thermosyphons and heat pipes: Overview of recent experiments and modelling approaches", International Journal of Thermal Sciences Vol. 72, pp. 1-17, 2013.

[9] Dadong Wang, Xiaoyu.Cui, "Experiment Research on Pulsating Heat Pipe with Different Mixtures Working Fluids", 21st International Symposium on Transport Phenomena2-5 November, Kaohsiung City, Taiwan, 2010.

[10] Pramod R. Pachghare, Ashish M. Mahalle, "Thermal Performance Of Closed Loop Pulsating Heat Pipe Using Pure And Binary Working Fluids", Frontiers In Heat Pipes, Global Digital Central, Vol. 3, 033002, 2012.

[11] Z.Q. Long, P. Zhang, "Heat transfer characteristics of thermosyphon with N_2–Ar binary mixture working fluid", International Journal of Heat and Mass Transfer, Vol. 63, pp. 204-215, 2013.

[12] Zhen-hua Liu, Xue-fei Yang, Guo-san Wang, Guang-liangGuo, "Influence of carbon nanotube suspension on the thermal performance of a miniature thermosyphon", International Journal of Heat and Mass Transfer, Vol. 53, pp. 1914-1920, 2010.

[13] Kanji Negisliiand Teruo Sawada, "Heat Transfer Performance ofan Inclined Two-Phase Closed Thermosyphon", Int. J. Heat Mass Transfer, Vol. 26, No.8, pp. 1207-1213, 1983.

[14] T. Payakaruk, P. Terdtoon, S. Ritthidech, "Correlations to predict heat transfer characteristics of an inclined closed two phase thermosyphon at normal operating conditions", Applied Thermal Engineering, Vol. 20, pp. 781-790, 2000.

[15] Nay ZarAung, Songjing Li, Numerical investigation on effect of riser diameter and inclination on system parameters in a two-phase closed loop thermosyphon solar water heater, Energy Conversion and Management, Vol. 75, pp. 25-35, 2013.

[16] S.H. Noie, "Heat transfer characteristics of a two-phase closed thermosyphon", Applied Thermal Engineering, Vol. 25, pp. 495-506, 2005.

[17] Te-En Tsai, Hsin-Hsuan Wu, Chih-Chung Chang, Sih-Li Chen, "Two-phase closed thermosyphon vapor-chamber system for electronic cooling", International Communications in Heat and Mass Transfer, Vol. 37, pp. 484-489, 2010.

[18] H. Mirshahi & M. Rahimi, "Experimental Study on the Effect of Heat Loads, Fill Ratio and Extra Volume on Performance of a Partial-Vacuumed Thermosyphon", Iranian Journal of Chemical Engineering, Vol. 6, No. 4 (autumn), pp. 15-26, 2009.

[19] B. Jiao, L.M. Qiu, "Investigation on the effect of filling ratio on the steady-state heat transfer performance of a vertical two phase closed thermosyphon". Applied Thermal Engineering, Vol. 28, pp. 1417–1426, 2008.