Comparative Analysis of Different Working Fluids in Thermosyphon Heat Pipe With or Without Fins

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Abstract: - In this paper, the effect of ammonia, chloroform and pure distilled water as different working fluids, its thermal performance is investigated in thermosyphon heat pipe with or without fins at closed room condition. One thermosyphon heat pipe without fins and anther thermosyphon heat pipe with internal circumferential fins on evaporator section and condenser section with internal and external circumferential fins. Model describes the detail thermal behavior and heat transfer of thermosyphon heat pipe with or without fins, initially by theoretical model and then by experimental model. These parameters included important tube size design parameters and thermal parameters (flow rate, heat loss, the effect of the finned heat pipe parameters after incorporating evaporation and condensation of the heat pipe working fluid. etc).

Keywords:- Thermosyphon Heat Pipe, Working Fluid, Fins.

I. INTRODUCTION

Thermosyphon heat pipe (Thermosyphon HP) is simple passive heat transfer device, which partially uses the gravity. In conventional heat pipe capillary effect is used to circulate the fluid but in thermosyphon HP gravity and density difference circulates the working fluid (WF). Density difference in WF assist WF to travel from evaporator to condenser and gravity assist WF to travel from condenser to evaporator. WF is filled up to evaporator volume under vacuum condition and the ratio of actual filled volume to the evaporator volume is known as the Filling Ratio (FR).

Thermosyphon HP has lots of advantage over conventional heat pipe like simple structure, smaller thermal resistance, low production cost. Some another advantage over other heat transfer devices such as absence of moving part, practically very less maintenance. Due to the wide range of advantages in thermosyphon HP has a wide range of application such as computer systems, solar system, electronic system, turbine blade cooling system, climatization process, preservation of permafrost etc.

Thermosyphon HP performance greatly depend upon the geometry, working conditions, FR, WF properties etc. There are many studies going on in these conditions, in order to improve the performance of thermosyphon HP.

II. LITERATURE REVIEW

Mustafa ali ersoz [1] studied the effects of six different fluids such as hexane, petroleum ether, chloroform, acetone, methanol and ethanol on exergy, energy performances for evacuated tube collector in thermosyphon HP with different fluid velocities as 2, 3, 4 (m/s). significant test were conducted on all six fluids and figured out chloroform is better in exergy efficiency and 4 (m/s) criteria . In another study, Mustafa ali ersoz[2] studies thermoeconomic analysis of three WF such as water, petroleum ether and ethanol. With study water proved to be the economic fluid and methanol fluid turned out to thermally beneficial one among the three. D. Jafari[3] studied the effect of different FR in thermosyphon HP such as 16%, 35%, 135%. Jafari also temperature distribution in the heat pipe in such FRs. Study shows thermosyphon HP gives greater performance in 35% or below it. Hua han[4] studied the the different between the performances of different WF such as water, methanol, ethanol and acetone in pulsating heat pipe. Han also conducted the series of experiment on different FR in pulsating heat pipe and found out that FR of 20% to 35% gives the best result possible. Han found out that deionised water is better in lower FRs but as FR increases methanol is better choice for WF. M. M. Sarfaraz[5] studied the effect of biologically produced nano fluid as a WF in thermosyphon HP. Sarfaraz used different percentage of nano fluid in found out that as percentage of nano fluid performance increases.

Y. Naresh[6] studied the effect of different fluid such as water, acetone etc. in internally finned thermosyphon HP at condenser section. Y. Naresh also studied the effect of different FR such as 50%, 20% and 80% and found out that 50% is the best one. Naresh also studied performance in different power. M. Arab[7] studied the effect of different WF such as acetone, methanol, pentane and ammonia for optimal performance in a concentric evacuated tube solar water heater. M. Arab also developed three hypothetical WF which gives the better results than real ones. Zhen-Hua Liu[8] studied the nano fluid for evacuated tubular high temperature air solar collector. Liu added the different percentage of nano fluids in water such as 0.8%, 1%, 1.2% and 1.5% and found out that 1.2% solution with water gives best result. Liu also studied heat flux effect in different temperature. P. Terdtoon[9] studied the effect of R-22, ethanol and water in thermosyphon HP. Terdtoon[10] also studied the effect of aspect ratio and

Bond number also FR too. Jiao studied the effect of nitrogen as a WF in thermosyphon HP. Jiao[11] also studied the effect of different FR. Sameer Khandekar[12] studied different WFs such as water and nano fluids mixed in water like Al_2O_3 , Cuo, leponide clay. Noe[13] studied the performance of Al_2O_3 /water in thermosyphon HP. Rohit S Nair[14] incorporated the internal circumferential fins to the condenser section which reduces the effective thermal resistance by way of enhanced condensation. Leonard M. Poplaski[15], working model contains fins outside the condenser which reduces the thermal resistance of the system results into higher thermal performance. He investigated by developing numerical model which accounts for the full external coolant domain, with and without external fins on the condenser, to investigate their influence on the thermal resistance network. Jae-Young Lee[16] studied the entrainment limit points which are affected by the L/D value of the heat pipe. The effect of L/D on the entrainment limits of large-L/D heat pipes was studied.

III. DESIGNING, MANUFACTURING AND EXPERIMENTAL PROCEDURE OF THERMOSYPHON HP

A. Designing of the Heat Pipe is Based on Power Input (550W) and Overall Properties of Water.

B. Manufacturing is done in two parts as follows:

- Without Fins heat pipe: Cylindrical pipe of 48 mm ID and 52 mm OD of length 800 mm. Then it is sealed from bottom by round shaped plate welding directly to pipe before that pipe and plate is grooved to fit into one another. On the top side round plate of same dimension is fitted and welded but an opening is made to connect the vacuum pump and to fill working fluid. Schematic showed in fig. No. 2.

- With Fins heat pipe: Cylindrical pipe of 48 mm ID and 52mm OD of length 800 mm. fins of thickness 2.2mm and 5 in no. is welded on three sides of pipe i.e. internally in evaporator and externally and internally in condenser. Fins were 2.2 mm width and 10 mm height inside and 15 mm height outside. To weld the fins inside the pipe was cut by laser cutting at 10 different places parallel to pipe axis then plates were welded. Along the pipe 320 mm and 380 mm in length respectively. Then it is sealed from top and bottom as like previous one. The Schematic of the manufactured section showed in fig. No. 3.

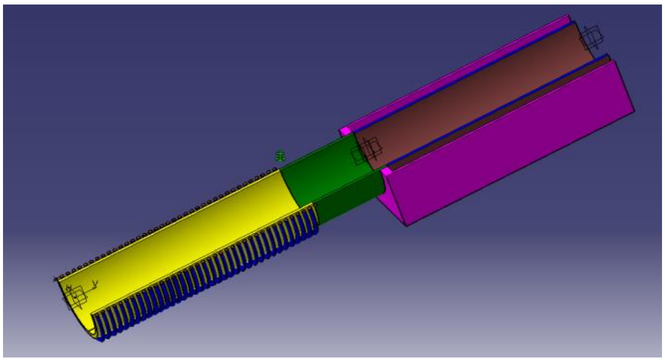

Fig. 1: Thermosyphon HP Without Fins.

C. Experimental procedure of Thermosyphon HP:

To obtain the performance analysis of thermosyphon HP, conventional thermosyphon HP is designed and manufactured. This study also compares the performance of ammonia, water, chloroform. The following image shows the conventional thermosyphon HP is made of mild steel having OD 52mm and ID 48mm. Evaporator section is 320mm, adiabatic section is 100 mm and condenser section is 380mm. Condenser section covering pipe is made of pvc pipe having OD 70mm and ID 68mm. Openings are given to the covering pipe for air inlet and air outlet. Heater power is 200W, but the experiment was performed at 125W and 5.6 (m/s) air velocity. Firstly water is charged into heat pipe later ammonia and then chloroform. The measurement of temperatures was carried out by K-type thermocouples to measure internal and external temperature. As shown condenser and evaporator have three equally distant internally mounted sensors with respect to their length (error ±0.25 °C). Also, in order to measure air velocities, an anemo meter (error ±0.2 ms^{-1}) was employed. Furthermore, for the purpose of measuring electricity consumption, electronic electricity meter (error ±0.1kWh) was put into use. Fig. no. 1 Thermosyphon HP and 4 shows the experimental setup as described.

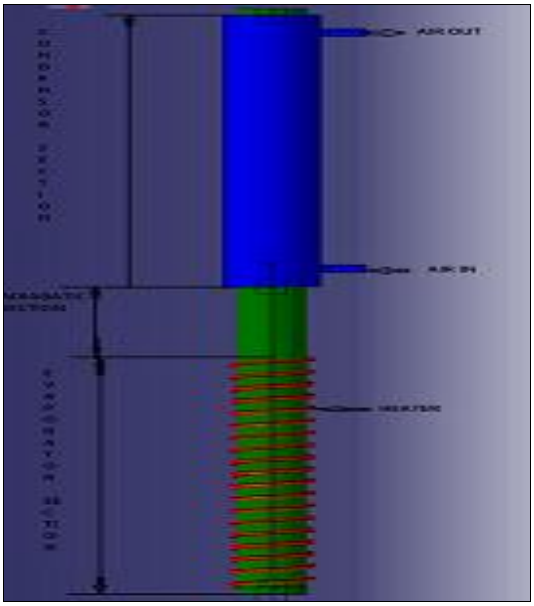

Fig. 2: Thermosyphon HP

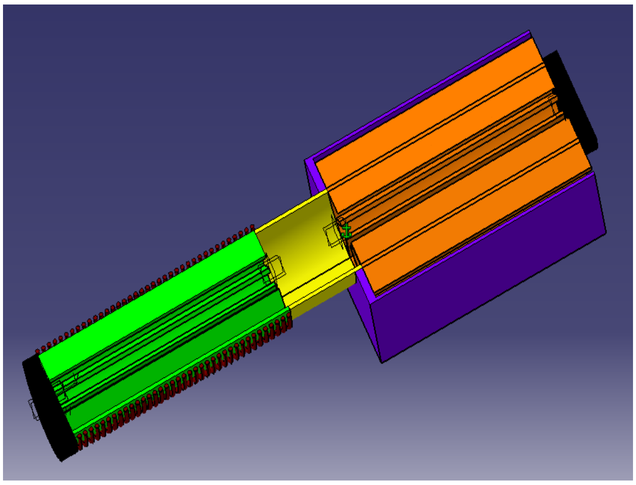

Fig. 3: Thermosyphon HP with Fins.

Fig.4: Thermosyphon HP Apparatus

IV. THERMODYNAMIC ANALYSES OF THERMOSYPHON HP:

In following heat pipe heater vaporizes the fluid in the evaporator section which then travels to condenser where WF rejects the heat to air and condenses and travels to evaporator again.
Hence, Heat rejected in the condenser = heat picked up by air
Energy,

$$Q_{cnd}= \rho_a V_a A_c C_{pa}(T_{a,out}- T_{a,in}) \quad ....(1)$$

Heat utilized in evaporation=

Heater power × Heating Efficiency= ..(2)

Energy efficiency =

Heat rejected by condenser / Heat utilized in Evaporation…(3)

Exergy analysis of thermosyphon HP:
By the law of thermodynamics,
Exergy available =

$$Exergy = mC_{pa}\left[\left(T_{a,out} - T_{a,in}\right) - T_a \ln\left(\frac{T_{a,out}}{T_{a,in}}\right)\right] \quad ....(4)$$

Exergy efficiency = Exergy/ Heat Supplied

Where,

Diameter of exit pipe, D_c = 20mm,
Hence, A_c = 0.000314 m^2
Density of air, ρ_a = 1.2754 kg/m^3
Velocity of air, V_a = 2.3 m/s
Heater power = 125 W
Heating efficiency = 0.9
Hence, total heat utilized = 125×0.9=112.5 W
$T_{a,out}$= temperature of air at outlet
$T_{a,in}$= temperature of air at inlet
Specific heat of air at const. press.,
Cp_a =1004 (W/m-K)

V. RESULT AND DISCUSSION

A. The experiments were performed separately on all three working fluids in two separate apparatus.

a). Water: The proposed graph (Fig. No.5) of energy efficiency obtained from the air jacket side which shows the difference between with fins and without fins. As with fins gives the extra surface area which results into 13.86% rise in energy efficiency. However on the exergy efficiency (Fig. No. 6) graph shows 33.54% rise in maximum available energy. The graph (Fig. No. 7) gives the temperature distribution in evaporator gives the extra temperature rise due to fins incorporated inside the evaporator. The average temperature rise in fin incorporate HP is 1°C against without fin. The Fig.

No. 8 gives the temperature distribution inside and air jacket side of the evaporator inside internal temperature of the working fluid (water) and outside temperature of the

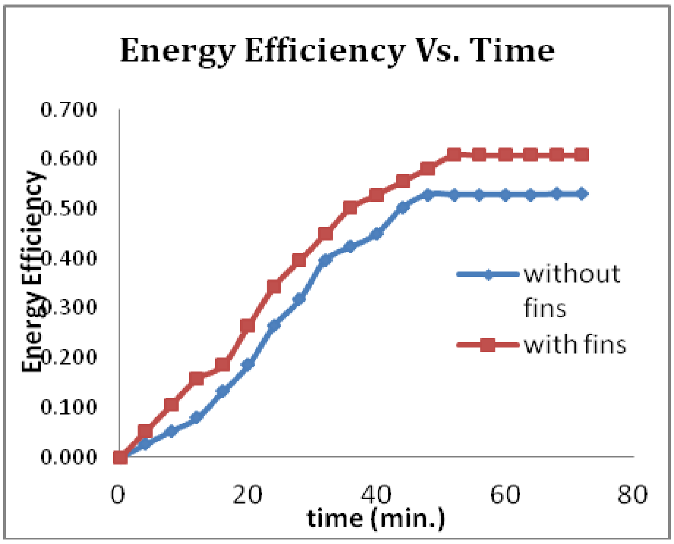

Fig. 5: Exergy Efficiency Vs. Time

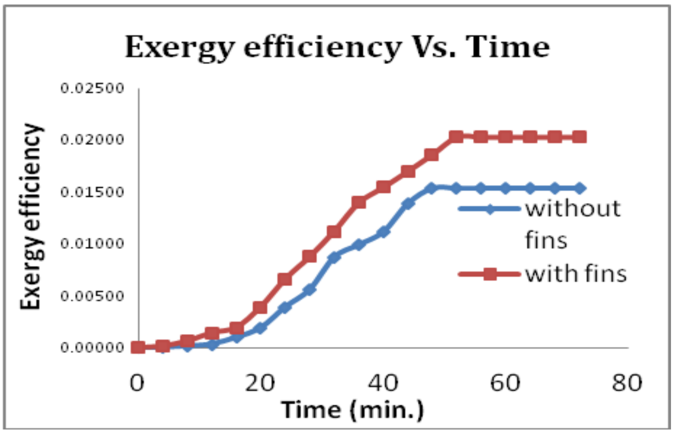

Fig. 6: Exergy Efficiency vs. Time

of the air jacket. As observed exit temperature difference between the without fin thermosyphon heat pipe is more than with fin thermosyphon heat pipe because fins provide more contact surface area from inside and outside hence fins side gives better heat exchange than without fins because difference between exit temperature of air and working fluid at exit is less in with fins analogy. Finally temperature distribution in thermosyphon heat pipe (Fig. No. 9) as we see evaporator side gives the higher temperature and condenser side lower temperature is seen with fins than without fins because as properties of fins defines evaporator side give more heat than without fins and condenser side reject more heat than without fin.

- Ammonia: The proposed graph (Fig. No.10) of energy efficiency obtained from the air jacket side which shows the difference between with fins and without fins. As with fins gives the extra surface area which results into 18.18% rise in energy efficiency. However on the exergy efficiency (Fig. No.11) graph shows 38.93% rise in maximum available energy.

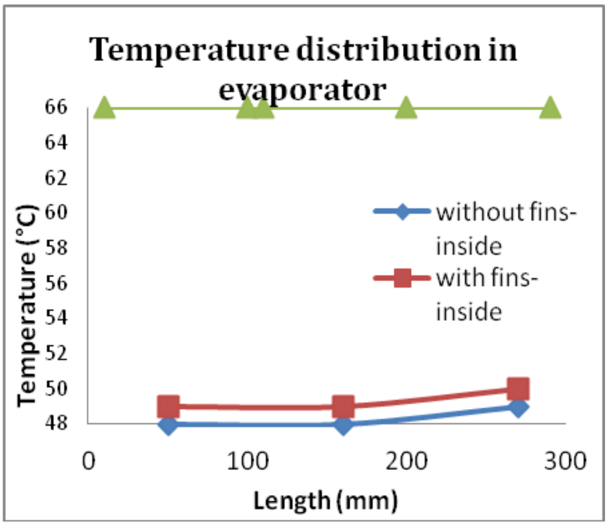

Fig. 7: Temperature Distribution in Evaporator

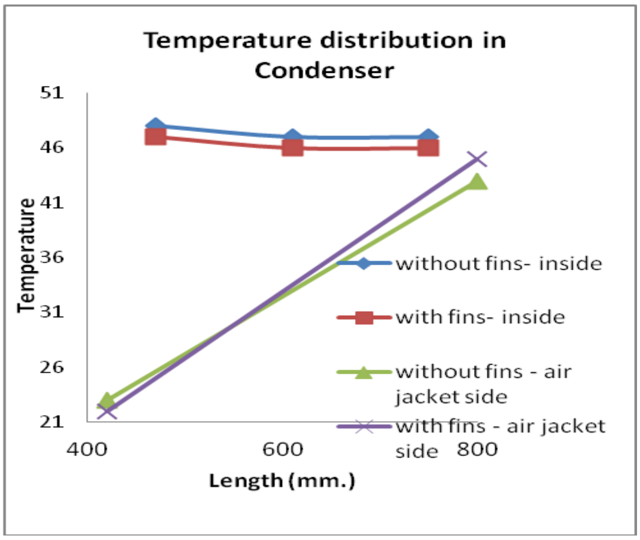

Fig. 8: Temperature distribution in Condenser

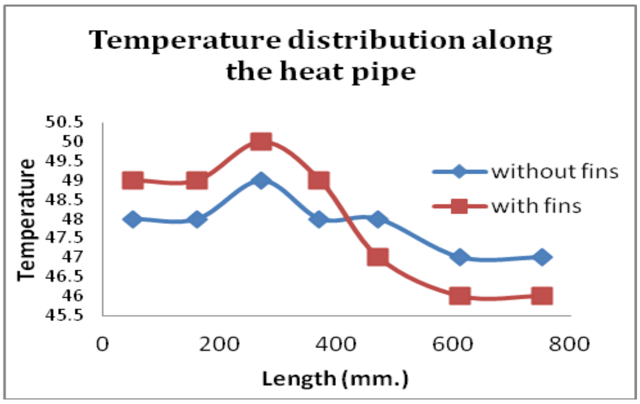

Fig. 9: Temperature distribution along the heat pipe

(Fig. No. 12) gives the temperature distribution in evaporator gives the extra temperature rise due to fins incorporated inside the evaporator.

The average temperature rise in fin incorporate HP is 1°C against without fin. The Fig. No. 13 gives the temperature distribution inside and air jacket side of the evaporator inside internal temperature of the working fluid (ammonia) and outside temperature of the of the air jacket. As observed exit temperature difference between the without fin thermosyphon heat pipe is more than with fin thermosyphon heat pipe because fins provide more contact surface area from inside and outside hence fins side gives better heat exchange than without fins because difference between exit temperature of air and working fluid at exit is less in with fins analogy. Finally temperature distribution in thermosyphon heat pipe (Fig. No. 14) as we see evaporator side gives the higher temperature and condenser side lower temperature is seen with fins than without fins because as properties of fins defines evaporator side give more heat than without fins and condenser side reject more heat than without fin.

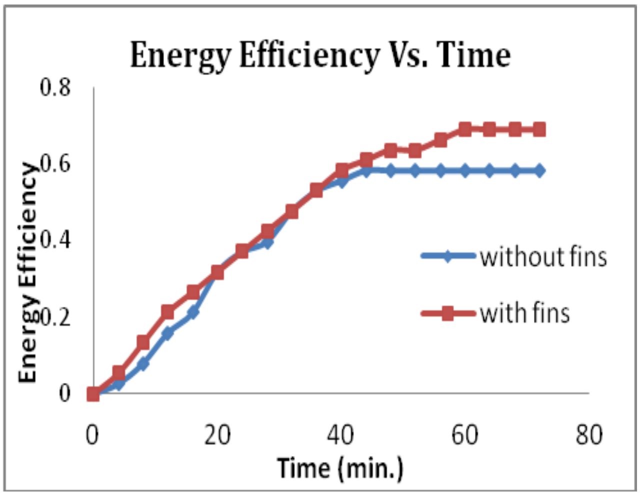

Fig. 10: Energy Efficiency Vs. Time

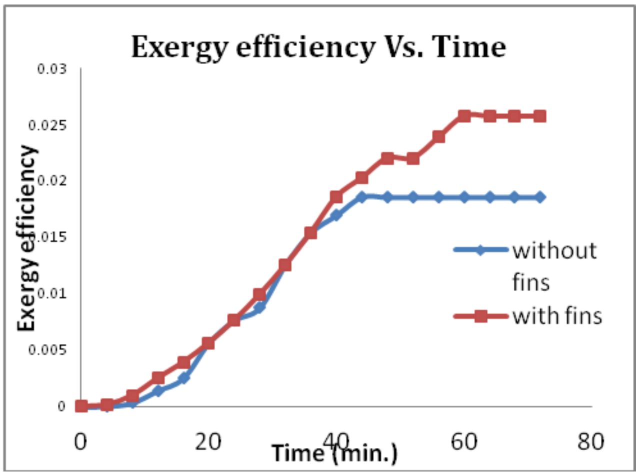

Fig. 11: Exergy Efficiency vs. Time

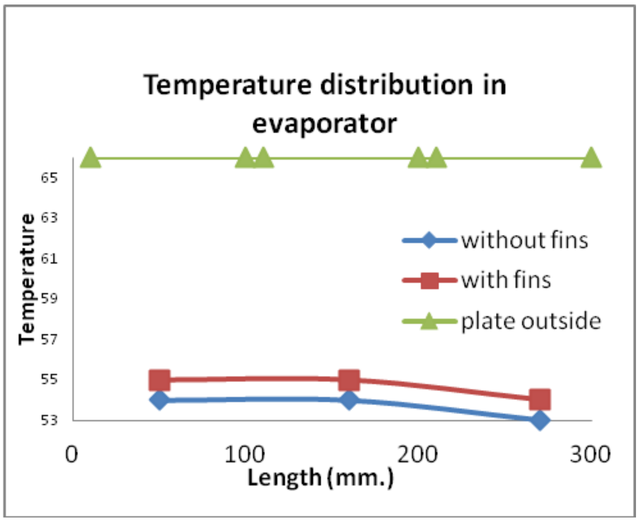

Fig. 12: Temperature Distribution in Evaporator

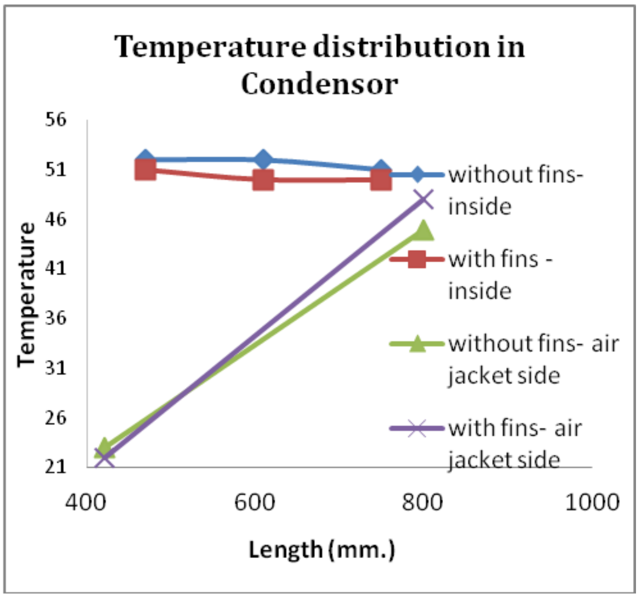

Fig. 13: Temperature Distribution in Condenser

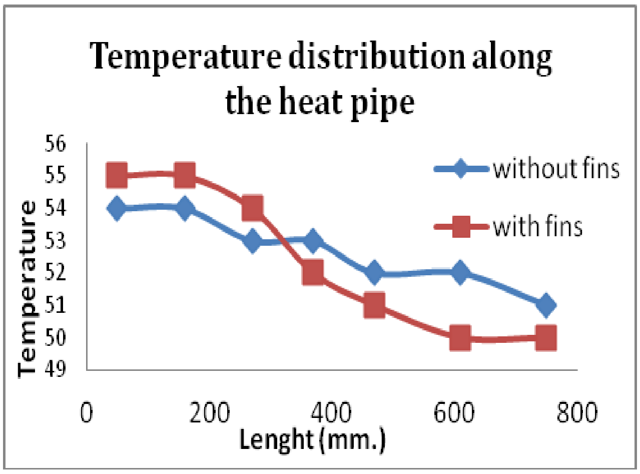

Fig. 14: Temperature Distribution along the Heat Pipe

- Chloroform: The proposed graph (Fig. No.15) of energy efficiency obtained from the air jacket side which shows the difference between with fins and without fins. As with fins gives the extra surface area which results into 20.83% rise in energy efficiency. However on the exergy efficiency (Fig. No.16) graph shows 44.59% rise in maximum available energy. (Fig. No. 17) gives the temperature distribution in evaporator gives the extra temperature rise due to fins incorporated inside the evaporator.

The average temperature rise in fin incorporate HP is 1°C against without fin. The Fig. No. 18 gives the temperature distribution inside and air jacket side of the evaporator inside internal temperature of the working fluid (chloroform) and outside temperature of the of the air jacket. As observed exit temperature difference between the without fin thermosyphon heat pipe is more than with fin thermosyphon heat pipe because fins provide more contact surface area from inside and outside hence fins side gives better heat exchange than without fins because difference between exit temperature of air and working fluid at exit is less in with fins analogy. Finally temperature distribution in thermosyphon heat pipe (Fig. No. 19) as we see evaporator side gives the higher temperature and condenser side lower temperature is seen with fins than without fins because as properties of fins defines evaporator side give more heat than without fins and condenser side reject more heat than without fin.

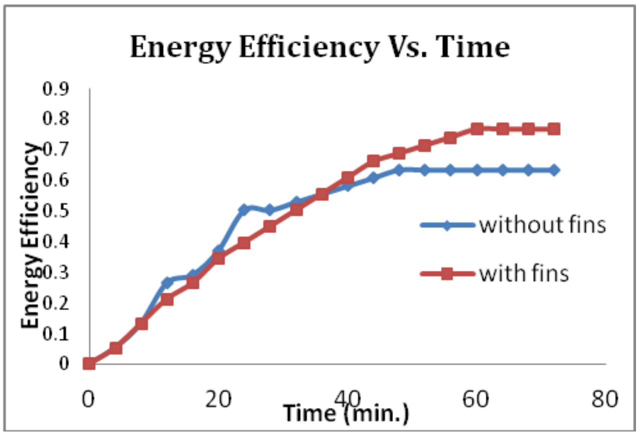

Fig. 15: Energy Efficiency Vs. Time

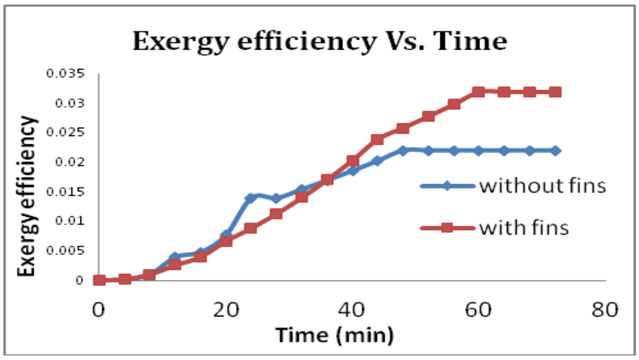

Fig. 16: Exergy Efficiency vs. Time

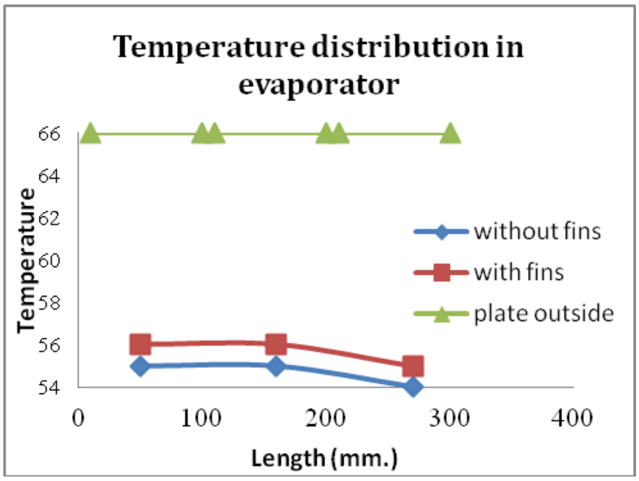

Fig. 17: Temperature Distribution in Evaporator

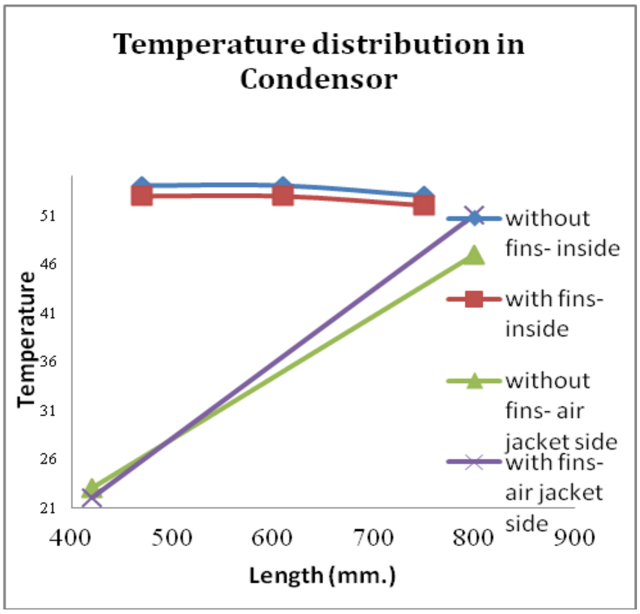

Fig. 18: Temperature Distribution in Condenser

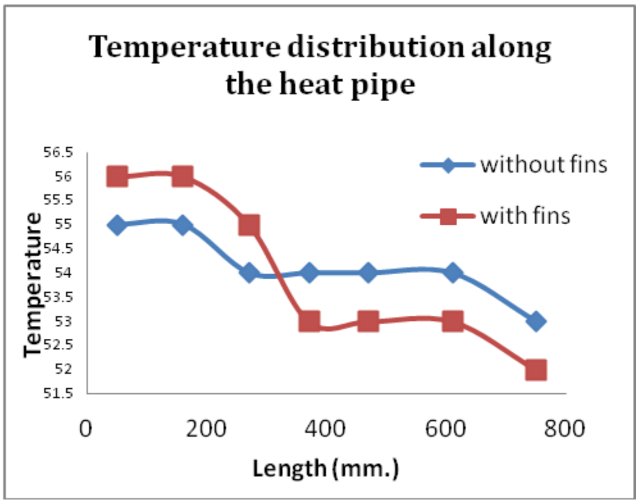

Fig. 19: Temperature Distribution along the Heat Pipe

Without fins is actually conventional thermosyphon heat pipe. (Fig. No. 20 - 23) In the same heat input and filling rate scenario, by using different working fluids- water, ammonia, chloroform the thermodynamic analysis of thermosyphon heat pipe were investigated experimentally in this paper. Considering the results of the analysis, the following main conclusions can be drawn from the present study is chloroform gives the highest exergy and energy.

Finally, exergy-based thermal analysis gives aid full information on defining, evaluating and minimizing the thermodynamics inefficiencies and their use for better design, analysis and improvement. This make the present paper a worthwhile source to show how thermal analysis is applied to such thermosyphon heat pipe systems.

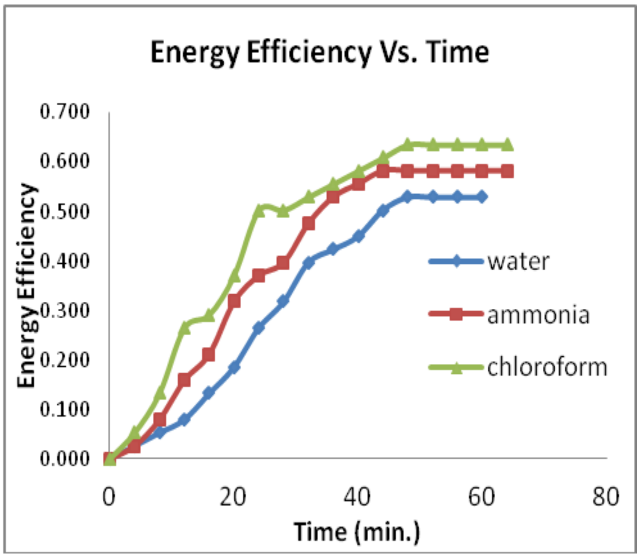

Fig. 20: Energy Efficiency vs. Time (Without Fins)

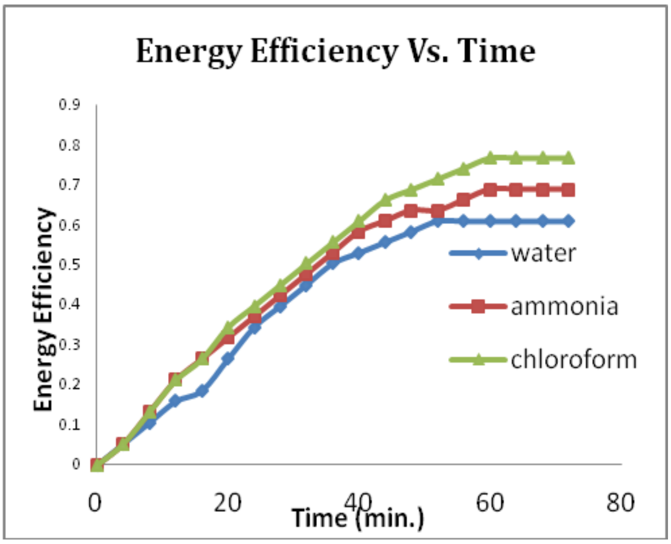

Fig. 21: Energy Efficiency vs. Time (With Fins)

VI. CONCLUSION

The rise in the energy efficiency when using water by applying fins is 13.86% and in available energy efficiency is 33.94%.The rise in the energy efficiency when using water by applying fins is 18.18% and in available energy efficiency is 38.93%. The rise in the energy efficiency when using water by applying fins is 20.83% and in available energy efficiency is 44.93%. Comparing three fluids energy efficiency and exergy efficiency can be concluded that chloroform is the best fluid in thermosyphon heat pipe among three of them after chloroform, ammonia is the second best working fluid using in thermosyphon heat pipe and finally water is the last choice of working fluid after ammonia and chloroform. Comparing temperatures in the evaporator area for all three fluids it is seen that with fins gives the best temperature rise in all fluids, which is the main advantage of applying the fins by increasing contact surface area. Comparing temperatures in the condenser area for all three fluids it is seen that with fins gives the best temperature fall in all fluids, which is the main advantage of applying the fins by increasing contact surface area. This reduces the exit temperature and top most temperature inside heat pipe difference in with fins than without fins.

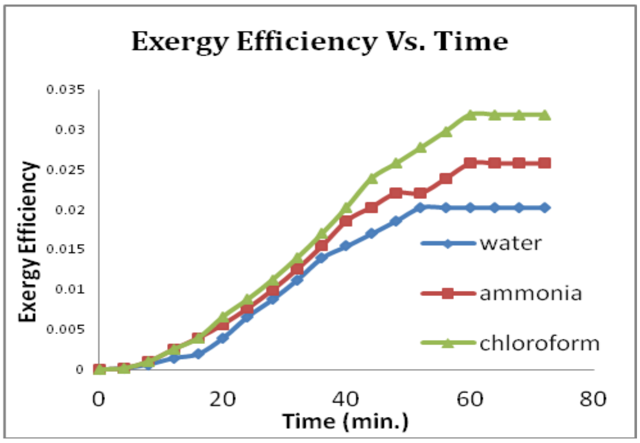

Fig. 22: Energy Efficiency vs. Time (Without Fins)

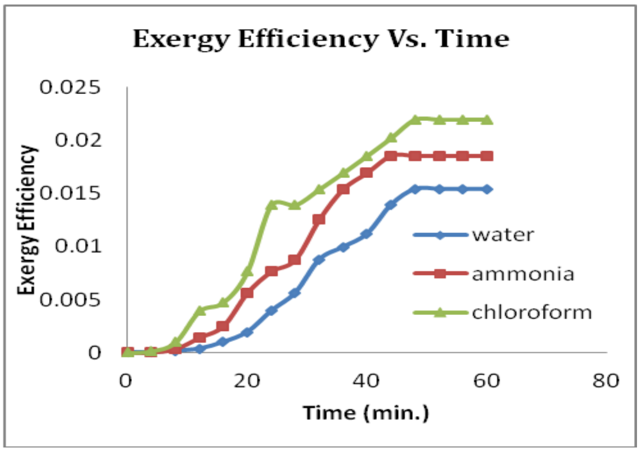

Fig . 23: Energy Efficiency vs. Time (With Fins)

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