PERFORMANCE ANALYSIS OF LOOP THERMOSYPHON SYSTEM

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ABSTRACT

Thermosyphon is a method of passive heat exchange, which circulates a fluid without the necessity of a mechanical pump. In modern era, number of the instruments generates more amount of heat such as computer devices, electronic equipment. Close loop two phase thermosyphon system working under gravity with condenser on the top and evaporator at the bottom. It does not require any pump to flow of working fluid from evaporator to condenser. This type of device is known as Close loop two phase thermosyphon. Thermo syphoning is used for circulation of liquids and volatile gases in heating and cooling applications such as heat pumps, water heaters, boilers and furnaces. For the proper working of CLTPT, it is necessary to design system. Optimally filled thermosyphon is recommended with small amount of working fluid to prevent breakdown of liquid film. Working fluid used as Methanol has high merit number. This system consists of an evaporator, condenser, capillary tube, non-return valve, pressure gauge. An evaporator is the heat exchanger device in which liquid absorbs its latent heat of vaporization from heating source and gets vaporized and discharged through the condenser through the vertical riser tubes. Condenser is used to condense fluid from vapor state to liquid state. After rejecting heat, liquid fluid flows under gravity to evaporator inlet. This cycle continued till maintains the required temperature in system. The readings were taken for every one hour time interval, the variation of temperature within the range of ±1^{0}C for the 40% and 50% filling ratio. Therefore, working experimental setup is giving satisfactory performance for repeatability test. Forced convection is effective than natural convection for 40% and 50% filling ratio. For various filling condition, Optimum filling ratio in case of natural convection and forced convection is 40%.

Keyword: - *Thermosyphon, heat, fluid, cooling*

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1. INTRODUCTION

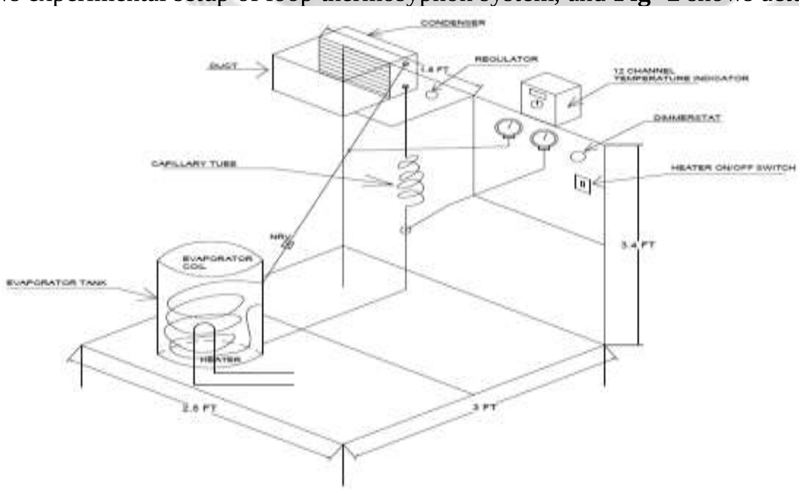
In modern era, number of the instruments generates more amount of heat such as computer devices, electronic equipment, Desert cooling system, etc. Close loop two phase thermosyphon system working under gravity with condenser on the top and evaporator at the bottom. It does not require any pump to flow of working fluid from evaporator to condenser. This type of device is known as Close loop two phase thermosyphon. As heat generation from various systems increased and there is limit on heat transfer rate in air cooling system the interest for using liquid cooling for high heat flux applications has risen. Thermosyphon cooling is an alternative liquid cooling technique in which heat is transferred as heat of vaporization from evaporator to condenser with a relatively small temperature difference. The thermosyphon has been proved as a promising heat transfer device with very high thermal conductance. High capacity passive cooling system studied in this project is a thermosyphon loop device that utilizes the loop thermosyphon heat transfer concept. This device is an assemblage of Evaporator, Condenser, Cooling liquid, Non-return valve and Reservoir charged with a liquid for removing heat. There are several different applications for thermosyphon loops such as Solar Water heater, geothermal system, Emergency machine rotor cooling, gas turbine blade cooling, and electronics device cooling. [1, 2]

The choice of the cooling technique is thus determined not only by the power dissipation but also by the junction temperature. A failure to maintain this temperature below the allowable limit results in the failure of the whole system. Therefore it is extremely important for effective thermal management of electronics system to precisely control the operating temperature of the critical components. Consequently, a large variety of cooling systems have been studied to maintain an applicable temperature for telecommunication equipment and many more systems. Active cooling systems need complex air filtration designs and high cost maintenance. They do not match the demand from the systems with a high thermal dissipation. Air cooling systems are disadvantaged by acoustic noise generation, electrical power consumption, weight addition and periodic maintenance requirements. [3]

Many researchers have been studied on the loop thermosyphon system with different filling ratio, working fluid, etc. S. H. Noie [4] investigated the effect of three parameters: input heat transfer rates (100< Q < 900W), the working fluid filling ratio and the evaporator lengths. The experimental boiling heat transfer coefficients were compared with existing correlations. They founded , for aspect ratio of 7.45 we get 90% of filling ratio, for aspect ratio of 11.8 we get 60% of filling ratio, for aspect ratio of 9.8 we get 30% filling ratio. Jiwon et al. [1] investigated different working fluids and four different surfaces are tested. Their result showed that optimum filling ratio is 40% with R1234ZE (E) is suitable for heat flux 116 W/cm^2. Alessandro et al. [2] reviewed on the heat and mass transfer in gravity assisted close loop thermosyphon system and correlates between mass flow rate and heat transfer. Small fluctuations gave differences in mass flow rate for same heat input. Rahmatollah et al. [5] investigated the thermal resistances for natural and forced convection. Natural convection gave a higher thermal resistance than forced convection due to the low heat transfer coefficient in free convection. Maian et al. [8] made analytical model for the determination of stability boundaries in a natural circulation single phase thermosyphon loop. Friction and heat transfer may be different in natural circulation conditions with respect to forced flow. H. Mirshahi et al. [17] investigated the effect of the heat flux, cooling water flow rate, fill ratio and extra volume on the overall performance of a partially vacuumed thermosyphon. Their result showed due to existence of trapped air and heat loads can have significant effects.
It is observed that characteristics of closed loop thermosyphon changes due to overfilled and under filled condition of working fluid. Evaporator temperature of under filled thermosyphon rises dramatically due to dry out However, slight increase in heat I/P will cause breakdown of condensate film. The overfilled thermosyphon possess a slightly slower thermal response time and to ensure optimal and stable steady state operation, optimally filled thermosyphon is recommended with small amount of working fluid to prevent breakdown of liquid film. Fluid filling ratio should be in range if 30% < F.R < 90%.

2. EXPERIMENTAL SETUP

Fig -1 shows experimental setup of loop thermosyphon system, and **Fig -2** shows actual photograph of experimental



setup.

Fig -1: Experimental setup

The setup composed of an evaporator at the bottom and air cooled condenser at the top and this system is operated by gravity. The principle of thermosyphon system is as: the liquid of working fluid is heated due to absorption of latent heat of vaporization and boiled in evaporator. After that the vapor of working fluid rises upward along a riser tube and enters in the condenser. Condenser rejects heat to atmosphere, as the vapors changes to liquid. Then, the liquid from the condenser returns to evaporator by the gravity. Evaporator is constructed using copper tubes as copper is having high thermal conductivity riser and down-comer tubes. Riser tube is connected between inlet which carries vaporized fluid and down comer tube is connected between the condensers through reservoir to inlet of evaporator which carry fluid in liquid state. The heating of water is carried out by using band heater attached at the bottom of evaporator. Two pressure gauges is fitted at riser and dimmer tube to show pressure readings. The whole thermosyphon system operated due to density difference.

Fig -2: Actual Experimental setup

2.1 Selection of working fluid

As per the literature survey, many researchers had investigated the effect of different working fluids on thermosyphon system. Thermosyphon system is studied with different working fluids like water ethanol, butane, methanol, etc. Different refrigerants were studied. Water is not used because of its highest boiling point. As phase change is difficult in system. So, there is need to find another refrigerant to get better thermal performance. Different CFC's which gives boiling point at 40^0C,47^0C, but theses CFC's phase out as they increases global warming potentials.

Methanol is best suitable choice of working fluid with its highest specific heat of vaporization. But this fluid should be selected as per global warming potential thermosyphon operation and performance depends on a large range of properties of fluid. This basic indicates a performance is given known as merit no. So. Methanol has high merit number. The properties of Methanol is given in **Table -1**

Table -1: Properties of Methanol [17]

Properties	**Methanol**
Boiling Point (^{0}C)	65
Melting Point (^{0}C)	-98
Useful Temp. Range	10 to 130
Thermal Conductivity at 300K (W/mK)	0.202
Latent heat of vaporization (hfg) (KJ/Kg)	1101
Dynamic Viscosity (μ) (Ns/m^2)	0.60*10^6
Density of liquid (ρ) (Kg/m^3)	750.8
Density of vapour (ρv) (Kg/m^3)	0.566

3. RESULT AND DISCUSSION

After design and manufacturing of loop thermosyphon system, different parameters like natural and forced convection with different filling ratio are studied. These parameters are studied at different bath temperatures are as:

3.1 Repeatability Test

Repeatability test is performed to check the performance of system.

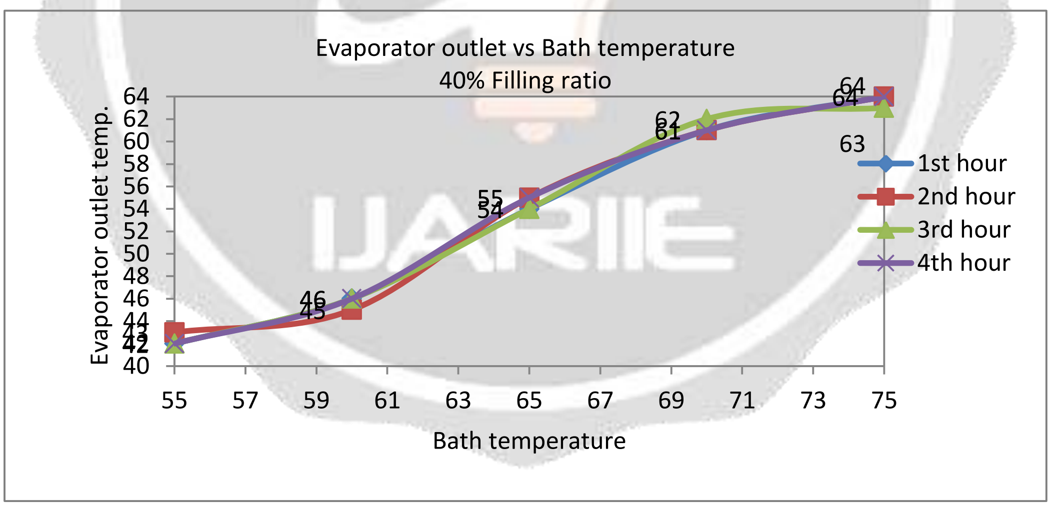


Fig -3: Evaporator outlet vs Bath temperature 40% Filling ratio

At a particular bath temperature, for different time interval, pressure and evaporation rate (latent heat of vaporization) remains same due to constant heat supplied. Latent heat decreases as bath temperature increases. Because as temperature increases, quantity of liquid methanol refrigerant decreases. Also, density decreases as bath temperature increases.

From **Fig -3**, and **Fig -4**, it can be seen that the variation of temperature within the range of ±1^{0}C for the 40% and 50% filling ratio. For every one hour time interval, all points are close to each other. Therefore, by considering the repeated readings, working experimental setup is giving satisfactory performance for repeatability test.

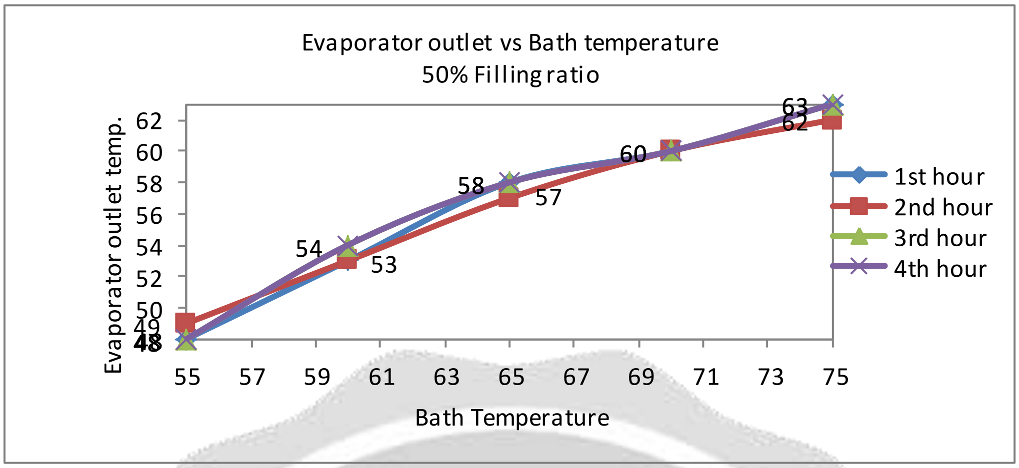


Fig -4: Evaporator outlet vs. Bath temperature 50% Filling ratio

3.2 Effect of Natural and Forced convection on thermal performance of loop thermosyphon system

Thermal performance of loop thermosyphon system consists of heat absorption, heat rejection by natural and forced convection. Different air velocities over the condenser give different effects.

The effect of natural convection and forced convection is mainly due to temperature difference of air over the condenser (fan). Air inlet temperature is not so varied but air outlet temperature is considerably varying. This air outlet temperature increases due to heat transfer or heat rejected by the condenser.Upto 65^{0}C temperature difference is somewhat same, but after 65^{0}C increases suddenly with high temperature difference by forced convection. For 50% F.R.quantity of refrigerant increases, natural convection is good at starting, but again temperature difference by forced convection increases rapidly. From **Fig -5** and **Fig -6** it is observed that, heat transfer rate is directly proportional to temperature difference. Higher temperature difference is effective. Figure shows that forced convection is better than natural convection for 40% and 50 % filling ratio.

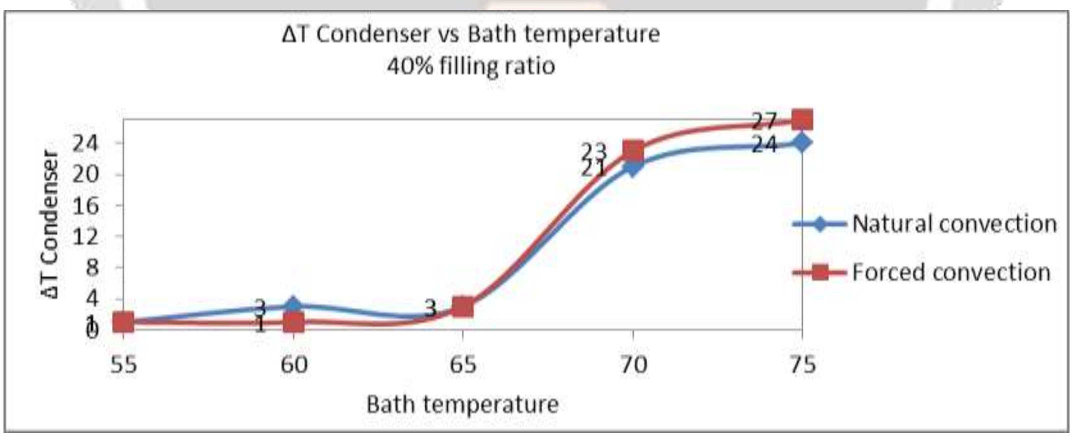


Fig -5: ΔT Condenser vs. Bath temperature 40% filling ratio

3.3 Effect of Filling Ratio on Thermal Performance of loop thermosyphon system

Overfilled and under filled conditions for which the working fluid with optimum case are investigated. The optimally filled thermosyphon has shortest response time and the lowest thermal resistance, however, a slight increase in the input power will cause breakdown of condensate film. The overfilled thermosyphon posses slower response and greater thermal resistance compared to the optimal condition.

The quantity of refrigerant filled in close loop thermosyphon system is greatly affected. For 40% filling ratio, the amount of refrigerant filled in the system is less as compared to 50% filling ratio.

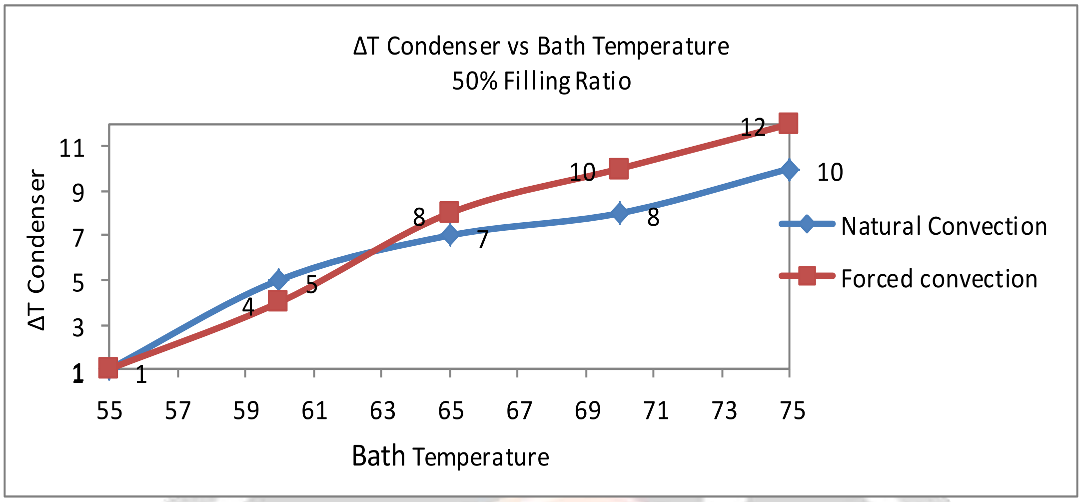


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Fig -6: ΔT Condenser vs. Bath temperature 50% filling ratio

From **Fig -7**, it can be seen that in natural convection, Evaporator outlet temperature for 40% and 50% filling ratio gives good heat absorption. Less amount of refrigerant will evaporate very early as compared to large amount of refrigerant. So optimum filling ratio in case of natural convection is 40%.

The quantity of refrigerant filled in close loop thermosyphon system is greatly affected. For 40% filling ratio, the amount of refrigerant filled in the system is less as compared to 50% filling ratio. Forced convection uses fan for passing air over condenser tubes. This rejects heat to air outlet and gives cooling effect.

From **Fig -8**, it can be seen that in Forced convection, Evaporator outlet temperature for 40% and 50% filling ratio gives good heat absorption. But 40% filling ratio gives high evaporator outlet temperature. It is always better to have high temperature at evaporator outlet. So optimum filling ratio in case of Forced convection is 40%.

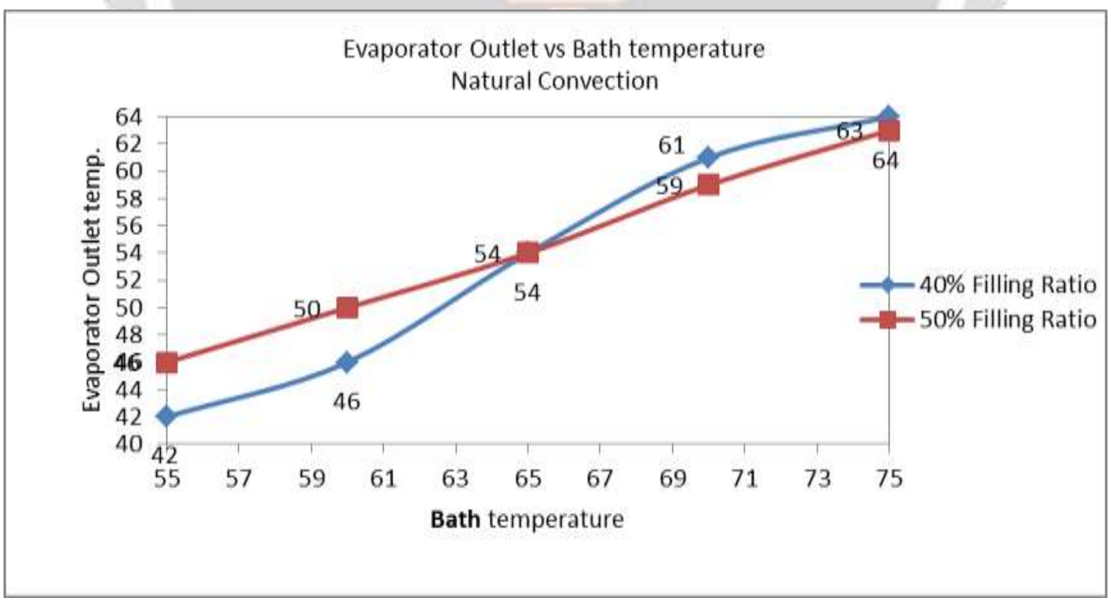

Fig -7: Evaporator outlet vs. Bath temperature Natural connvection

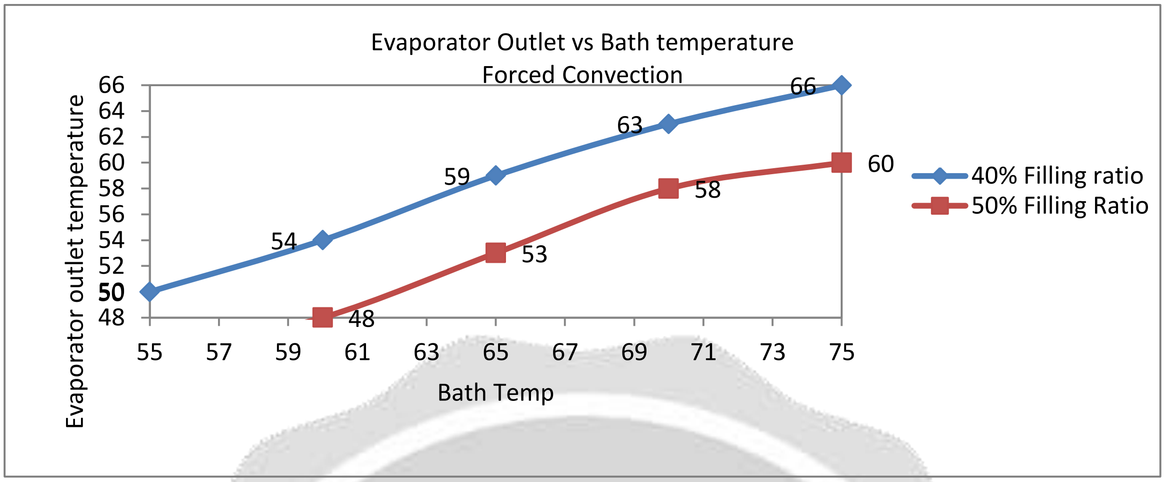

Fig -8: Evaporator outlet vs. Bath temperature Forced convection

3.4 Effect of Natural convection and Force convection on loop thermosyphon system

Convective heat transfer is one of the major types of heat source and convection is also a major mode of mass transfer in fluids. Convection can be takes by natural convection and forced convection.

The rate of heat transfer from condenser depends on natural convection and forced convection. This heat transfer also depends on convective heat transfer coefficients and temperature difference. For natural convection temperature difference is less as compared to forced convection. Upto 65^{0}C natural and forced convection rejects same heat due to large quantity of liquid refrigerant in the system, but after 65^{0}C Forced convection is rejecting more heat.

In a previous study **[4]**, it is found that, condenser heat transfer increases as bath temperature increases in forced and natural convection. From **Fig -9**, for condenser side heat rejection in forced convection is better than natural convection for 50% filling ratio.

The rate of heat transfer from condenser depends on natural convection and forced convection. This heat transfer also depends on convective heat transfer coefficients and temperature difference. For natural convection temperature difference is less as compared to forced convection. For 40% filling ratio contains less quantity of refrigerant. So there is high temperature difference in forced convection which rejects more heat in forced convection.

In a previous study **[4]**, it is found that, condenser heat transfer increases as bath temperature increases. For **Fig -10**, but for condenser side heat rejection in forced convection is better than natural convection for 40% filling ratio.

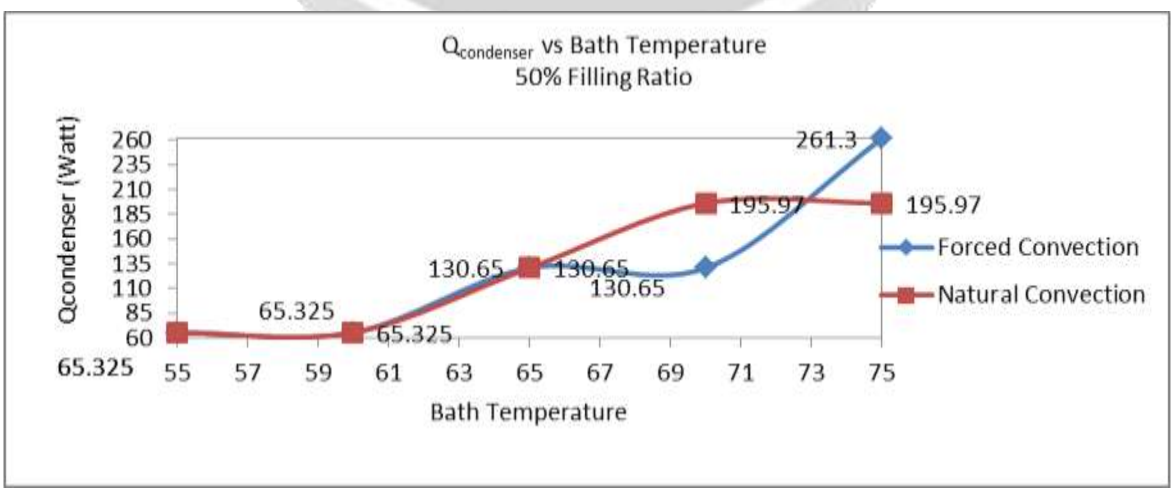

Fig -9: $Q_{condenser}$ vs. Bath Temperature 50% Filling Ratio

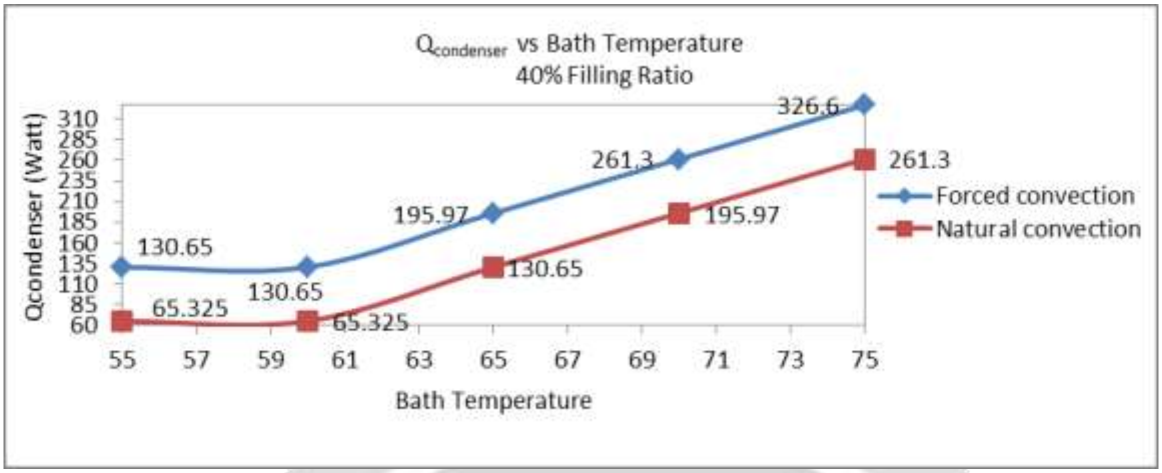

Fig -10: $Q_{condenser}$ vs. Bath Temperature 40% Filling Ratio

4. CONCLUSIONS

The closed loop thermosyphon system is analyzed with Methanol as a refrigerant. In present work the performance of loop thermosyphon system is experimentally investigated. During the investigation, the effect of filling ratio and modes of convection is considered. The modes of convection as natural convection and forced convection is taken into account. The following conclusions can be drawn from the analysis and discussion of the results:

1. For every one hour time interval, the variation of temperature within the range of $\pm1^0$C for the 40% and 50% filling ratio. Therefore, working experimental setup is giving satisfactory performance for repeatability test.
2. As bath temperature increases, temperature difference also gets increased. Higher temperature difference is effective for thermal analysis of loop thermosyphon. Forced convection is effective than natural convection for 40% and 50% filling ratio.
3. Overfilled and under filled conditions for which the working fluid with optimum case are investigated. So from various filling conditions, optimum filling ratio in case of natural convection and forced convection is 40%.
4. Convection is also a major mode of mass transfer in fluids. Condenser side heat rejection in forced convection is better than natural convection for 40% and 50% filling ratio.

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