Performance Analysis of Sintered Copper Heat Pipe Tower Cooler Based Liquid Cooled Heat Exchanger

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Abstract : In the miniaturized world of electronic equipments excess heat generation has become a threat to the life span of electronic devices. Conventionally air based cooling is followed but due to some of its drawbacks, its performance compared with that of liquid cooling system is poor. Hence needs arises for such a critical management of heat which ultimately demands for the development of liquid cooling system. The conventional liquid cooling system utilizes aluminium and copper plates. In order to achieve a moderate performance the temperature gradient must be sufficiently high enough else for low temperature gradient, they show poor performance. A tower cooler using Heat pipe is the proposed solution to the above stated problem which provides a copper heat pipe tower integrated with radial spiral fin (e.g. micro-channel technology) and metal sintered copper heat pipe construction for better performance. The working fluid to be used in the copper heat pipe is ethanol -methanol (60-40 %) with filling ratio of 50 % of volume of heat pipe. Test rig is fabricated and testing is done by varying flow rate of oil (medium for liquid heat load) and flow rate of air. The research work consists of heat load evaluation for application specific, heat pipe selection, design and fabrication of heat pipe enclosure tower as to surface area and number of fins, steady state thermal analysis is done using Ansys workbench 16.0.

***IndexTerms* - Cooling capacity, Energy consumption, Heat pipe, liquid cooled heat exchanger, sintered copper heat pipe, wick structure.**

I. INTRODUCTION

A heat pipe is a device which is used to transport the heat from end to another end. Heat pipe are also known as Superconductor because of its capacity to transfer heat with nearly no heat loss. It includes a sealed container made up of aluminum or copper. The inner surfaces of heat pipe have a capillary wicking material. The flow of condensate takes place by the driving force of capillary wick. The heat pipe performance is depended on the wick type and its quality. Depending upon the application, the selection of type of wick is done. Heat pipe consists of 3 components:

1. The working fluid
2. The container
3. The wick or capillary structure

The liquid in the container is under its own pressure which enters the capillary material through the pores due to which the internal surfaces get wet. The heat applied to the heat pipe surface at any point causes the liquid to boil and vaporize from that point. Due to this the liquid takes up the latent heat of vaporization. The high pressure gas moves to the cold region within the sealed container where it gets condensed. During this condensation the gas give away the latent heat of vaporization and moves heat from the one end to another end of heat pipe. A compared to copper, heat pipes have thousands times more thermal conductivity. The term " Axial Power Rating (APR)" is used to specify the heat transfer capacity of heat pipe. It is the energy that is moving along the pipe in axial direction. The larger the heat pipe diameters have greater APR whereas longer heat pipe have less APR. Heat pipes can be made in almost any size and shape.

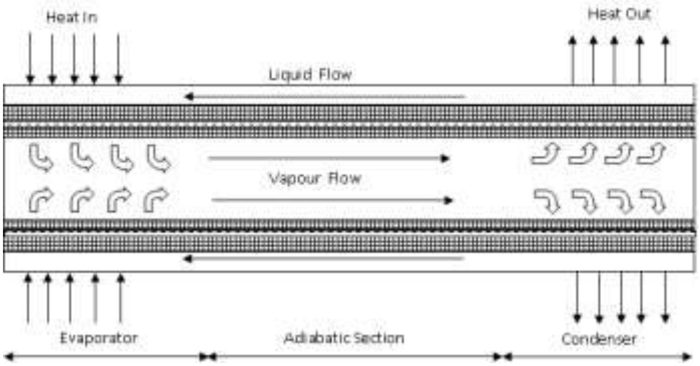


Fig. 1.Working Principle of Heat Pipe

The heat generation from all the electronic devices and circuit is in excess and thus to improve the reliability and prevent failure, an efficient thermal management system is needed. The quantum of heat released is equal to the power input, if there is no heat interaction. There are various methods of cooling such as different kinds of heat sinks, thermoelectric coolers, air systems and fans, heat pipes, and many more. In case where the temperature of the surrounding is very low as compared to the temperature of system, then the system or device needs to be heated up in order to have proper functionality of the device or system.

1.1 Sintered Copper Heat Pipe Configuration

This allows round, shaped, heat pipe configured to fit into the tightest of applications. For example, heat pipes can be held onto to mounting holes. For the best thermal contact, heat pipes are press fitted or adhesive bonded into the metallic heat sinks making them strong enough to withstand and survive the toughest temperature extremes and vibration environments.

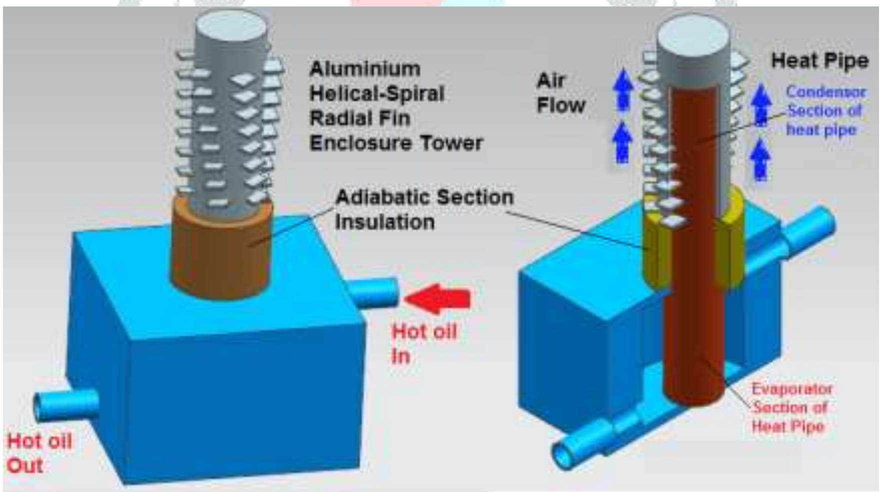


Fig.2. Heat pipe Embedded Liquid cooling system with helical spiral radial fin enclosure tower

Fig.3. Internal Structure of Sintered Copper Heat Pipe

II. Literature Review

Randeep Singh, et al. (2007) [1]This research work involves experimental investigation on a copper miniature loop heat pipe (mLHP) with a flat disk form of evaporator, diameter 30 mm with thickness of 10-mm, designed for thermal management of pc microprocessors.The least value of thermal resistance for the mLHP is 0.17 C/W with evaporator thermal resistance of 0.06 C/W. it is summarised from the outcomes of the present study that a mLHP with flat evaporator geometry will be effectively used for the thermal management of equipment as well as notebooks with restricted area and high heat flux chipsets. The results additionally make sure the superior heat transfer characteristics of the copper-water configuration in mLHPs.

Sumit Kumar Rai and K K Jain (2012) [2] The research was carried on the HPHE at various tilt angles form the horizontal and at various heating fluid temperatures at inlet of evaporator. The variation of surrounding temperature was also considered. The heat transport rate of the HPHE increases marginally as the Reynolds number of heating fluid increases in the evaporator section because the condenser heat transfer coefficient does not increase significantly. At any tilt angle and any heating fluid temperature the highest heat transport rate from the HPHE is achieved.

Shailesh Prajapati, Prajesh Patel (2014) [3] In this research the study of heat pipe, copper pipe and stainless steel pipe is carried out. Electric heater as a heat source is used to power the 3 pipes. Variation of heat is done with Dimmer stat suitable heat is supplied and by means of temperature sensors, temperatures were noted at particular length. The results indicated a very good heat transfer stainless steel heat pipe and also in ansys workbench, computational analysis carried out and cfx module and the result from the experiment is validated from it.

Vishnu Agarwal, et al. (2015)[4] This is a review on heat pipes applications in different fields. Here 8 major applications are elaborated which represents that heat pipe has a wide application range. This paper makes the heat pipe technology much more familiar and aware different fields where heat control is needed.

Lian Zhang and Yu Feng Zhang (2016) [5] In this paper, the results represented that , a heat pipe heat exchanger (HPHX) saves over 80% of the energy during the air conditioning operating hours.. There was a reduction in overall energy rate from 3.2% to 4.5%. The Energy saving potential of a laboratory was higher than that of buildings. A combined ventilation and recovery system would further leads to efficient system.

Xiaoqin Sun, et al. (2016) [6] To extract the heat from electronic device, a thermoelectric cooling (TEC) system was developed. Also a gravity assistant heat pipe (GAHP) as a heat sink is attached on the hot side of the thermoelectric cooling module in order to improve the system performance. Designing and testing of prototype was done under different conditions and results reflected that there was an improvement in cooling capacity by approx 73.54% and the electricity consumption decreased by 42.20% to produce the same quantum of cold energy.

III. Problem Statement

The liquid cooling using extrusion of aluminium or copper on a cylindrical cavity and cooling fluid circulated through it is a common practice in industry, though the method is innovative and increases the surface area of the heat exchanger there are certain problems faced while using the device which are namely:

1. Very large foot print as the size of the plates is considerably large to increase the surface area the device. Hence occupies very large space making the equipment of application bulky and heavy.
2. Device is prone to leakages as large liquid volumes are needed to handle more heat flux.
3. Suitable to high heat gradients i.e. large temperature difference is desired for proper operation.
4. Relatively higher cost.

IV. Experimental Setup

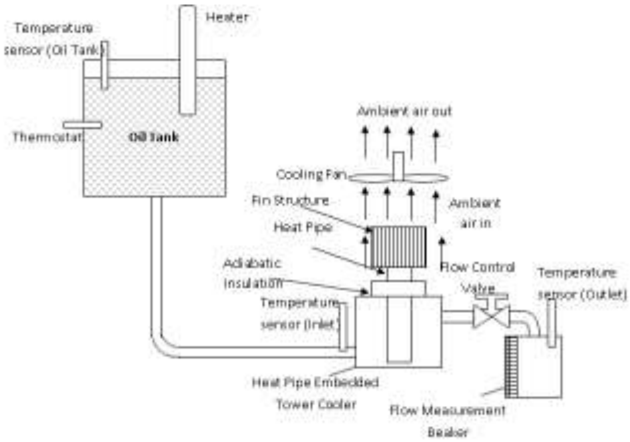


Fig. 4.Schematic representation of Experimental Setup

Fig. 5. Actual Photograph of Experimental Setup

Fig. 4 shows the schematic representation of experimental setup. The setup consists of an oil tank embedded with a heater, temperature sensor and a thermostat. The heater as a heat source increases the temperature of oil to a desired value. The hot oil then passes through passages to reach to the Heat pipe embedded tower cooler chamber. In this chamber the evaporator section of heat pipe is submerged and the condenser section present outside the chamber carries a Radial spiral type of fin structure to increase the heat dissipation rate. Further to aggravate the process of heat transfer, forced cooling by means of a cooling fan is achieved. A flow control valve is used to monitor the flow rate of oil. The temperature of the oil coming out of the heat pipe embedded tower cooler chamber is measured by means of a temperature sensor.

V. Design Methodology

A. Selection of Heat Pipe:

1. Material of pipe: Copper
2. Wick structure: Porous Sintered / Copper wire mesh
3. Material of wick: Copper
4. Working Fluid: Ethanol+ Methanol (60-40) ratio
5. Size: 20 mm diameter
6. Length: 75 mm

7. Filling ratio: 50 % volume of pipe

8. Maximum Watts at 200C and 300C is 210W and 240W respectively.

B. Cold air circulation fan: Square cooling fan 100mm size, thickness 25mm, 2400RPM, 69 CFM max, 35dB noise level, bearing style sleeve type, 12V DC, 340 mA.

C. Temperature Sensors: Electronic temperature sensing element with wire probe. Display is integrated to the measurement unit.

D. Heater: Immersion rod heater 250 watt

E. Flow control Valve = 1/4 " BSP

F. Thermostat: Capillary type 30 to 300 degree Celsius

G. Input Data:

Table 1.Oil grade: SAE 20W50 (Thermophysical properties)

T Temp.(K)	ρ density (kg/m^3)	c_p specific heat (kJ/Kg-K)	μ viscosity (N-s/m²)	ν kinematic viscosity ($10^{-4}m^2/s$)	k thermal conductivity (W/m-K)	α thermal diffusivity ($10^{-8}m^2/s$)	Pr Prandtl number	β volume expansion coefficient ($10^{-4}/K$)
340	860	2.08	0.053	0.62	0.139	7.77	795	7
360	848	2.16	0.025	0.30	0.137	7.48	395	7
380	836	2.25	0.014	0.17	0.136	7.23	230	7
400	824	2.34	0.009	0.11	0.134	6.95	155	7

1. Heat load on the heat pipe system = 240 watt

2. Assuming that the heat load is in accordance to a 0.5 hp device with only 60% conversion efficiency.

3. Temperature increase = heat generation rate (watt/min) / (oil specific heat (kj/kgK) * (oil flow rate (kg/min))

4. Specific heat of oil =2.34 (kj/kgK)

5. Maximum Allowable Temperature rise = 200C ---- target value

6. Flow rate through system = 324 / 2.34 x 103 x 20 = 0.007 Kg/sec

7. Flow rate through system = 0.415 kg/min = 0.52 lpm

Thus using reverse engineering considering a mass flow rate of 1 lpm, the minimum capacity required by the heat pipe system will be as follows

8. Wattage of Heat pipe = (0.824 /60) *2340 *20 = 642 watt

Factor of Safety = 642/324 =1.928

Thus the heat pipe system selected is having a factor of safety = 2

Thus to be on a safer side and still achieve good results with given system of input we shall assume that a heat pipe capable to transfer 200 watt and above will be suitable for the application.

H. Procedure for test and trial of equipment:

1. Heat the oil in the tank with heater up to desired temperature (say 900 C).

2. Note Hot oil inlet temperature (Thi).

3. Open valve partially and collect oil in beaker (50 ml).

4. Measure stop watch time required to fill 50 ml in beaker.

5. Take hot oil outlet temperature (Tho).

6. Change the valve opening to record other readings.
7. Form observation table.

VI. Results And discussions

A. Analysis and Calculations:

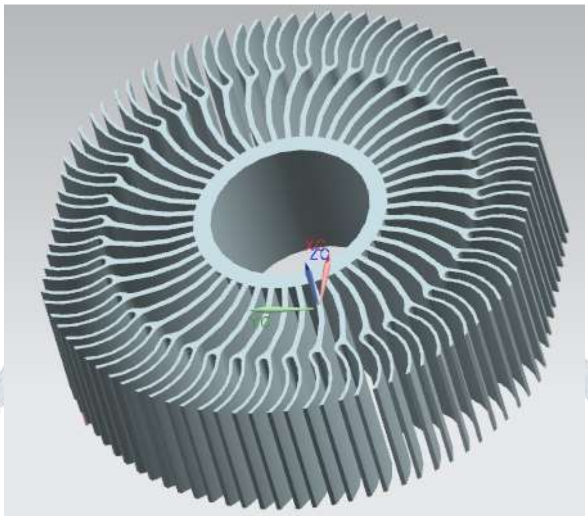


Fig. 6.Spiral Fin Model

Detailed Mass Properties

Analysis calculated using accuracy of 0.990000000

Information Units in kg - mm

Density	=	0.000002660
Volume	=	45749.346346060
Area	=	106970.325514622
Mass	=	0.121693261

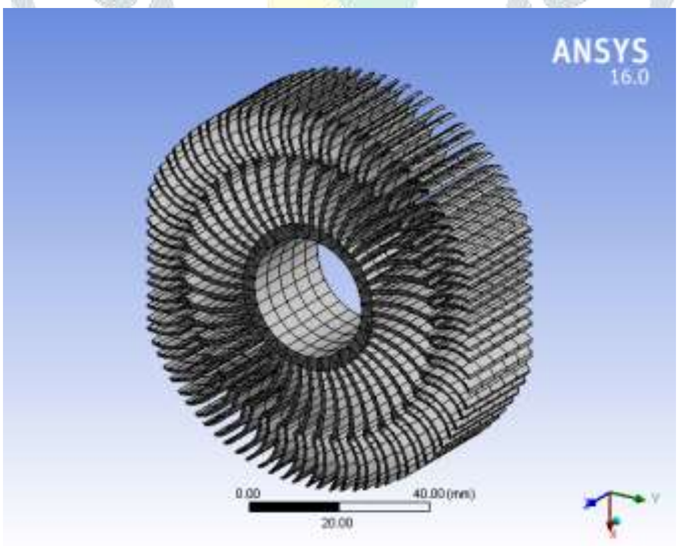


Fig. 7.Spiral Fin Meshed model

Ansys Workbench free mesher was used to generate the mesh, first the meshing was done and then the generate command was used to apply it , details of the mesh parameter set by the workbench have been displayed below:

Statistics

Nodes	48441
Elements	6920
Mesh Metric	None

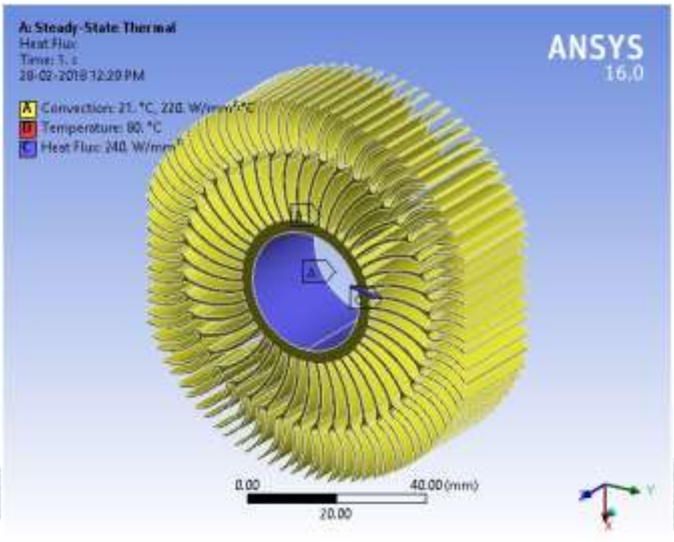


Fig. 8.Boundary condition applied to model for analysis

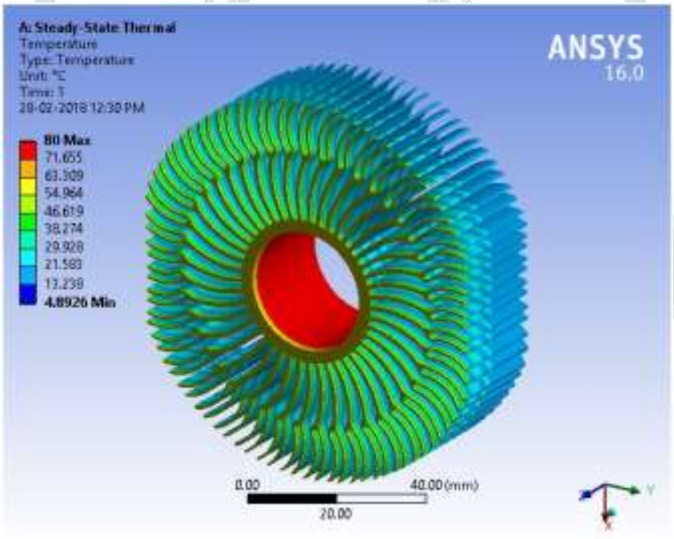


Fig. 9.Temperature Variation Contour

Temperature variation contour is obtained when given boundary condition are applied to the problem. The results obtained from ANSYS software simulation for temperature contour is shown in figure . From figure we can say that as fluid entered into aluminium block firstly it comes in contact with inner member therefore maximum temperature exists there. After that it is entered the fin section where heat is dissipated.

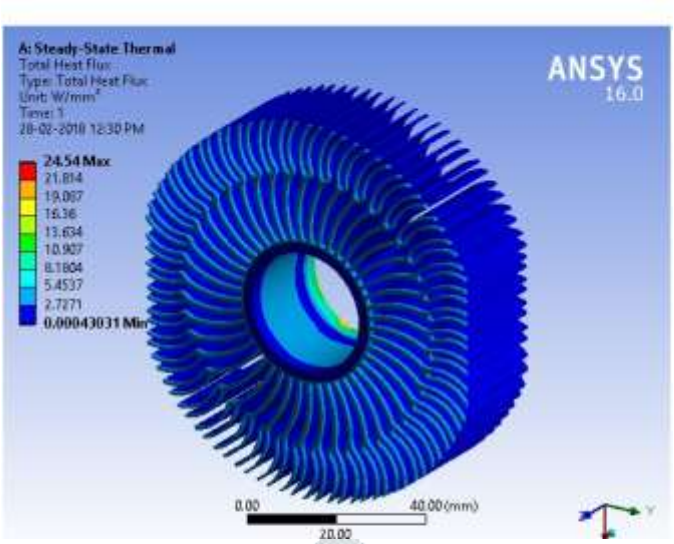


Fig. 10.heat flux carried by the fin system

The figure above gives the heat flux carried by the fin system which is close to 24.54 watt very close to the required heat dissipation ability of the system.

B. Mass Flow Rate of Hot Oil

Table 2: Mass flow rate of hot oil

Sr. No.	Volume in Beaker (ml)	Time (Sec)	Mass Flow Rate (Kg/sec)
1	50	19	0.002231579
2	50	16	0.00265
3	50	14	0.003028571
4	50	12	0.003533333
5	50	10	0.00424
6	50	7	0.006057143

C. Temperature Readings

Table 3: Temperature Readings of Oil and Air

Sr. No.	Cold air Inlet Temp. (T_{ci}) ^{0}C	Cold air outlet Temp (T_{ce}) ^{0}C	Hot oil Inlet Temp. (T_{hi}) ^{0}C	Hot oil outlet Temp. (T_{he}) ^{0}C
1	28.5	28.8	80	74
2	28.5	29.4	80	69.8
3	28.5	30.1	80	62.7
4	28.5	30.9	80	58.6
5	28.5	31.4	80	54.3
6	28.5	32.1	80	52.5

1. The amount of thermal energy transferred is calculated as

$Q= m_h Cp_h \Delta T$ (hot fluid)

where, m_h is the mass flow rate of hot fluid in kg/sec

Cp_h is the specific heat of hot fluid in j/kg-K

ΔT is the temperature difference at inlet and outlet of hot fluid in K

Q is the heat transfer rate in watts

2. Similarly Q= $m_cCp_c\Delta T$ (cold fluid)

where, m_c is the massflow rate of cold fluid in kg/sec

Cp_h is the specific heat of cold fluid in j/kg-K

ΔT is the temperature difference at outlet and inlet of cold fluid in K

3. Since, from the measurements both inlet and outlet temperatures are known, the Log Mean Temperature Difference is calculated for counter flow as:

$$LMTD = \frac{(Thi-Tce) - (The-Tci)}{\ln[(Thi-Tce)/(The-Tci)]}$$

4. Capacity Ratio = $\frac{(mxCp)small}{(mxCp)large}$

5. At steady state, the overall heat transfer coefficient is calculated as:

U = Q/(AxLMTD)

6. Effectiveness is the ratio of actual heat transfer to the maximum possible heat transfer.

Effectiveness = Q/Qmax

Since (mcp)hot < (mcp)cold , so

Effectiveness = (Thi-The) /(Thi-Tci) or

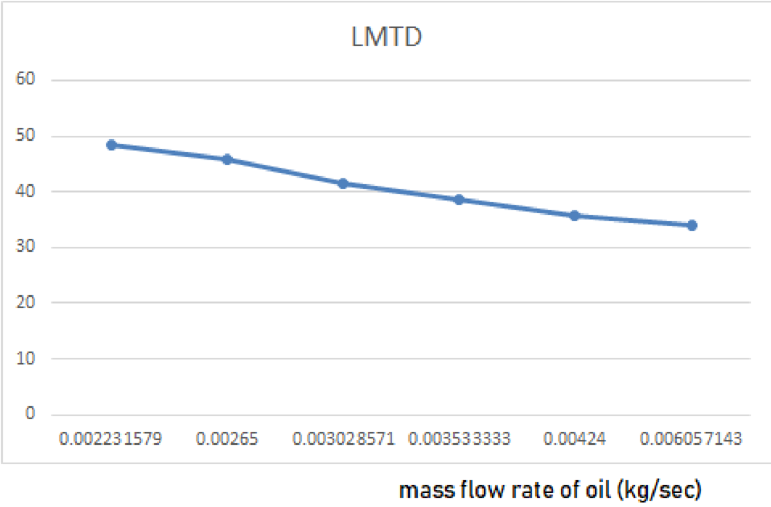
if (mcp)hot >(mcp)cold , then

Effectiveness = (Tce-Tci) /(Thi-Tci)

Table 4: Result Table for Sintered Copper Heat Pipe

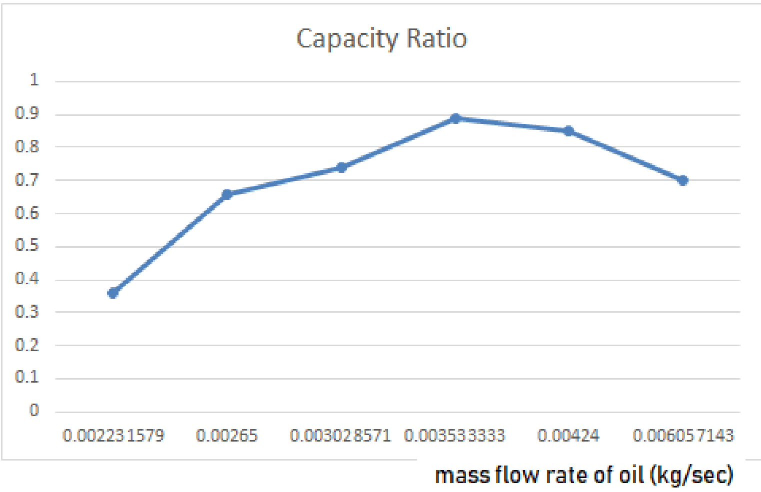
Sr. No	Hot oil Inlet temperature (Thi)	Hot oil outlet temperature (Tho)	Cold air Inlet temperature (Tci)	Cold air Outlet temperature (Tco)	LMTD	Effectiveness	Capacity ratio	Overall HTC U W/m2K
1	80	74	28.5	28.8	48.3	0.12	0.36	2.00
2	80	69.8	28.5	29.4	45.8	0.2	0.66	7.90
3	80	62.7	28.5	30.1	41.4	0.34	0.74	18.85
4	80	58.6	28.5	30.9	38.6	0.42	0.89	34.92
5	80	54.3	28.5	31.4	35.7	0.5	0.85	52.1
6	80	52.5	28.5	32.1	34.1	0.54	0.70	67.3

Graph of LMTD Vs Mass flow rate



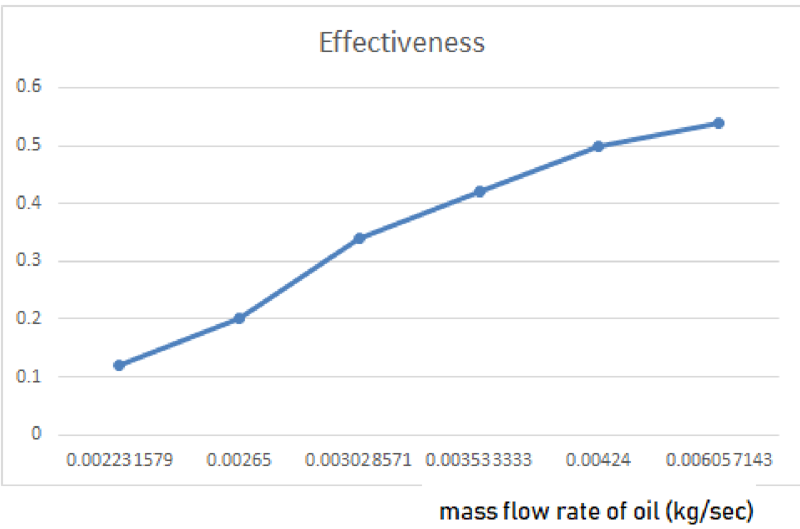
LMTD is seen to drop with increase in the flow rate of oil

<u>Graph of Capacity ratio Vs mass flow rate</u>



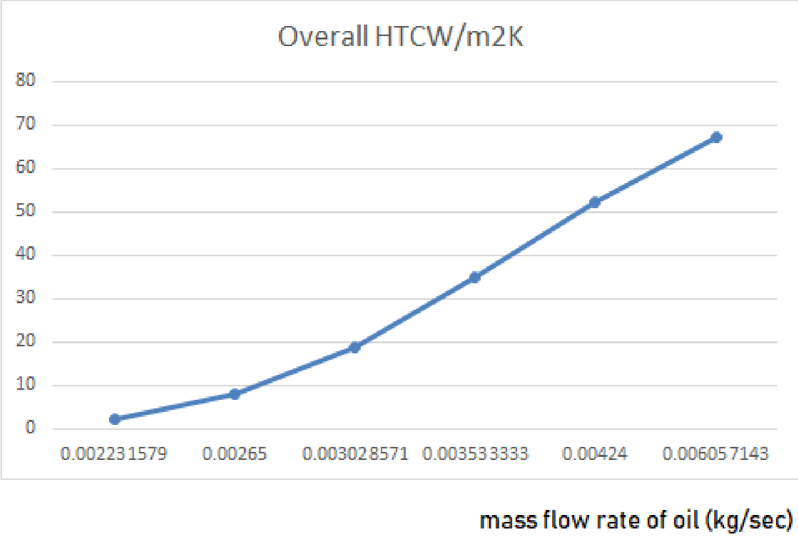
The capacity ratio is seen to increase with mass flow rate upto a certain limit and then drops slightly indicating an optimal flow rate of oil.

<u>Graph of Effectiveness Vs mass flow rate</u>



The effectiveness of the heat exchanger increases steadily with increase in flow rate of oil

<u>Graph of Overall Heat transfer coefficient Vs mass flow rate</u>



The overall heat transfer coefficient of the heat exchanger increases steadily with increase in mass flow rate of oil.

D. Document of Analysis For Sintered Mesh Heat Pipe

Selection of Process Parameters:

Based on the experimental results discussed above, important parameters have been selected to analyze their effect on various machining parameters using Taguchi's design of experiment technique. In present work, two input parameters namely flow rate of oil, flow rate of oil control have been investigated during testing for maximum temperature gradient of oil.

Table 5. Process variables and their levels

Parameter	Level-1	Level-2	Level-3	Level -4	Level -5
Mass flow of oil	0.002232	0.00265	0.003029	0.003533	0.00424
Mass flow of air	0.0154	0.0185	0.023	0.028	0.0323

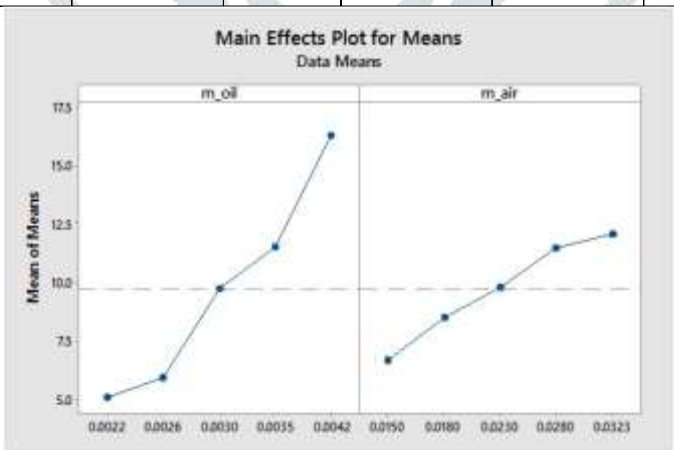


Fig. 11.Main Effects Plot for Means

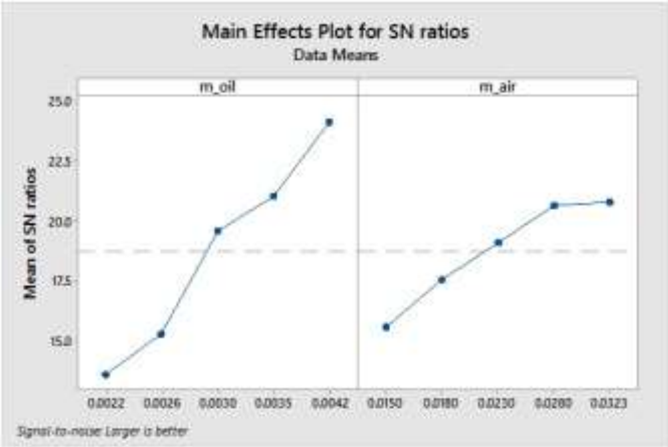


Fig. 12.Main Effects Plot for SN ratios

From the graph of S/N ratio the optimal performance of the Sintered copper heat pipe system will be obtained when the mass flow rate of oil will be 0.0042 kg/sec and mass flow rate of air will be 0.0323 kg/sec

VII. CONCLUSION

1. LMTD is seen to drop with increase in the flow rate of oil.
2. Capacity ratio is seen to increase upto a particular limit and then drops.
3. Effectiveness increases steadily with increase in mass flow rate.
4. Overall heat transfer coefficient increases with increase in mass flow rate.
5. Optimal performance of the Sintered copper heat pipe system will be obtained when the mass flow rate of oil will be 0.0042 kg/sec and mass flow rate of air will be 0.0323 kg/sec

A simple, compact, high efficiency , low cost device will be developed, so also a new technology of heat pipe embedded tower cooler will be learnt through the project. The research will provide the industry with a new device to solve over heat problems in many machines in many applications.

REFERENCES

[1] Randeep Singh, Aliakbar Akbarzadeh, Chris Dixon, Mastaka Mochizuki, and Roger R. Riehl, (2007). “Miniature Loop Heat Pipe With Flat Evaporator for Cooling Computer CPU”, IEEE Transactions On Components And Packaging Technologies, Vol. 30, No. 1, March 2007

[2] Sumit Kumar Rai and K K Jain (2012). “Evaluation Of The Thermal Performance Of Heat Pipe Heat Exchanger Under Natural Convection”, International Journal of Mechanical Engineering and Robotics Research, Vol. 1, No. 2, July 2012

[3] Shailesh Prajapati, Prajesh Patel (2014). “Performance Behaviour of Copper Pipe, Stainless Steel pipe and Steel Heat Pipe”, International Journal of Engineering and Management Research Volume-4, Issue-2, April-2014 Pn 277-281

[4] Vishnu Agarwal, Dr. Sudhir Jain, Keerti Vyas,Ginni Jain (2015). “A Review Paper on Role of Heat Pipes in Cooling”, International Journal of Emerging Trends in Electrical and Electronics,Vol. 11, Issue. 2, June 2015

[5] Lian Zhang and Yu Feng Zhang (2016). "Research on Heat Recovery Technology for Reducing the Energy Consumption of Dedicated Ventilation Systems: An Application to the Operating Model of a Laboratory", Energies 2016, 9, 24; doi:10.3390/en9010024

[6] Xiaoqin Suna, Yanjia Yanga, Hongliang Zhanga, Huiwei Sia, Liang Huanga, Shuguang Liaob, Xiaosong Gua (2016). "Experimental research of a thermoelectric cooling system integrated with gravity assistant heat pipe for cooling electronic devices", The 8th International Conference on Applied Energy – ICAE2016, Energy Procedia 105 (2017) 4909 – 4914