DESIGN DEVELOPMENT AND THERMAL ANALYSIS OF HEAT PIPE ENHANCED COOLING SYSTEM FOR HYDRAULIC OIL TANK

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ABSTRACT:- *The hydraulic power pack is a type of equipment that users want to save energy and operate reliably with minimal maintenance. A hydraulic oil tank is designed to prevent the hydraulic oil from overheating. Due to inefficiency, the working fluid will heat up. It is very important for the design of a hydraulic system that keeps the oil temperature within a limited range. The developed equipment was first modeled with Unigraphix Nx8, and the ANSYS 16.0 Helix-Fin heat transfer workstation was used for static thermal analysis. The hydraulic oil tank in the cooling system is built into the hydraulic oil tank through heat pipes and innovative fin design. The hydraulic oil tank must be connected in series with the oil cooler module on the surface of the oil tank. The use of heat pipe will result in better overall HTC whereas the innovative fin structure provides the largest area in the smallest space. The flow is provided by a system for effective oil flow through the oil cooling system.*

Key Words: *Heat pipe, cooling system, oil tank.*

1. INTRODUCTION:-

The hydraulic fluid temperature in operation is caused by a malfunction. Inefficiency leads to loss of input energy, which is converted into heat. The heat load of the hydraulic system is equal to the total lost power (PL) for malfunction and can be defined as:

Total power loss is given by loss of power in the pump, power loss in valves, power loss in plumbing & power loss in actuators.

Heat dissipation is the major part of the hydraulic system. So, the heat dissipation rate should be as high as possible. Allowing oil temperatures to exceed the recommended limits may reduce system life due to improper lubrication, high internal leakage, high cavitation risk, and damage. The heat dissipated is less than the total input power lost to heat, the hydraulic system will finally overheat. The cooling capacity applied is usually between 25 and 40 percent of the input capacity, depending on the type of compression system. Maintaining a lower temperature also helps to ensure that oil and other substances are more durable & improves system efficiency.

Hydraulic Fluid Temperature:-

Hydraulic fluid temperatures above 82°C are severely harmful to water components and speed up oil degradation. While the operation of any hydraulic system at temperatures above 82°C should be avoided, the temperature of the liquid is very high when the viscosity falls beneath the average number of components of the hydraulic system. This can occur beneath 82°C, depending on the viscosity of the fluid.

The advantages of this system can be-

Increase the heat transfer rate by removing the hidden heat by 100% in addition to the reasonable temperature emitted by the previous system. A compact system requires less space, zero maintenance, and no chances of leakage. Maximum surface in minimum space & lower manufacturing cost.

The applications of this system can be-

Hydraulic power pack. electronic control panel cooling. Hydraulic machinery with the heavy heat load. Electronic circuit cooling.

2. PROBLEM DEFINITION:-

2.1. Problem Statement:-

Overheating is the most common problem regarding hydraulic equipment. Unlike leaks, which measure number one, the causes of overheating and their remedies are not well understood by maintenance workers.

2.2. Solution:-

The improved concept of a heat pump for cooling hydraulic oil cooling oil using three modules of heat pipe with a radial blower system is shown in the fig below.

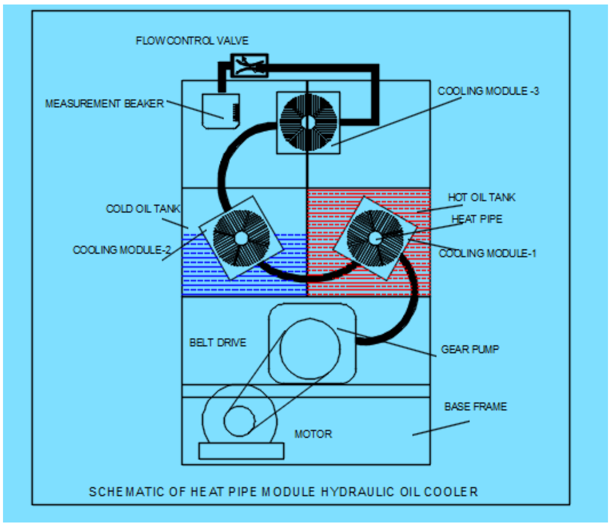

Fig. 1- Bloch diagram of heat pipe module system.

2.3 Project Objectives:-

In this research work, the design and manufacture of heat pipe enhanced oil cooler modules with crossflow structures are done. Also, test rig development with overheating conditions analogous to 0.5 HP power pack. Then use a heat pipe cooler on the test bench to test the hydraulic oil with the increased crossflow to determine the following heat exchanger parameters.-

LMTD, effectiveness & overall HTC comparison with mass flow rate.

3. LITERATURE SURVEY:-

CR Kamthane *et al.* The model is designed to test the performance of heat pipes. Since this model is designed for oil cooling, the test was carried out when the temperature difference between the inside and outside of the oil was 45°C to 80°C. A module is approximately 200 W, and natural convection is 120 W. By using heat pipes, oil cooling is more effective than using traditional fans on pipes that transport hot oil.

B. Orret *et al.* (2015) Research has been conducted on the waste heat recovery system of automobiles using thermoelectric generators and heat pipes. In this study, they studied that the heat pipe reduces the thermal resistance between the thermoelectric generator and the gas; they also found that the pressure loss in the flowing gas is reduced due to the reduction of the fin area through the heat pipe. Because the design of the heat pipe is more flexible, it can be used to adjust the temperature of the thermoelectric generator. TEG system and temperature control and increase design flexibility.

Ashish A. Wankhead et al. Oil inlet and outlet temperature drops, that is, oil temperature decreases with oil flow.

Chintan D. Patel *et al.* The conclusion is that the active fluid and heat transfer of PHP is significantly higher than that of dry PHP. Due to its low thermal conductivity, PHP's performance in gravity is better than PHP's performance in anti-gravity. Usually, PHP assumes a volume occupancy rate of 40% instead of 80%.

Rahul Royal. Sadly *et. al.* (2013) In this paper, two types of heat pipes were studied, in that they using working fluid as ammonia, two aluminum that is pipes **-** one heat pipe is with a wick structure and another is with no wick structure. The wick which is used is made of screen mesh. The heat pipes are placed at the same angles in the horizontal direction.

Ramesh Ganuga Penta *et.al.* (2017). The study is performed to study the possibility of using heat pipe cooling in the application of drilling. For a heat pipe drill configuration, the effect of different geometrical parameters was considered, such as depth of the heat pipe within the drill, heat pipe diameter, heat flux input magnitude, and length of the heat input zone, etc.

V.M. Aguiarin *et.al.* (2018) In this paper, experimentally research was made in thermal analysis of a finned thermosyphon for heat exchanger applications. The thermosyphon was manufactured from a copper tube. The working fluid used was water with a filling ratio of 40% of the evaporator volume. The condenser cooling takes place by forced convection (air).

Urmila C. Dhainje, A.G. Kamble In this article, the author draws the following conclusions from research work: As the flow rate increases, the LMTD decreases, and the efficiency, flow rate, and overall heat transfer coefficient are proportional to mass flow rate. A compact, efficient and inexpensive device was developed, so a new heat pipe technology with an oil cooler was studied in this work.

Bharat M. Jibhakate, Dr. M. Basavaraj In this paper, the author discussed the detailed study of heat pipes on different parameters such as container, wick/capillary structure, working fluid, tilt angle, and fill ratios. Heat pipes are devices that transfer heat from a heat source to a heat sink. i.e. evaporator to condenser over a long distance which is a passive device. Heat transfer process from heat pipe - Thermal energy at the evaporator section, vaporizes the fluid. Then this vaporized fluid goes to the condenser section. At the condenser section, vapor condensation takes place, this vapor condensate back to liquid (latent heat), then condensate liquid, from the condenser section (travels along with wick) via. capillary action to the evaporator section.

K. M. Stone In this paper, the author gives a detailed discussion on the application of enhanced heat transfer surfaces to compact heat exchangers. In that the inspiration for heat transfer and the principles are discussed. Finally, some plate-fin enhancement geometries are discussed.

Leonard L. Vasiliev This paper discussed the heat pipes are very flexible systems having effective thermal control. For electronic components cooling and space two-phase thermal control systems, micro heat pipes are used. For modern heat exchangers loop heat pipes, pulsating heat pipes and sorption heat pipes are used. In thermal power plants, to preheating the secondary–primary air required for combustion of fuel in the boiler using the energy available in exhaust gases, heat pipe air preheaters are used.

4. CONSTRUCTION AND WORKING:-

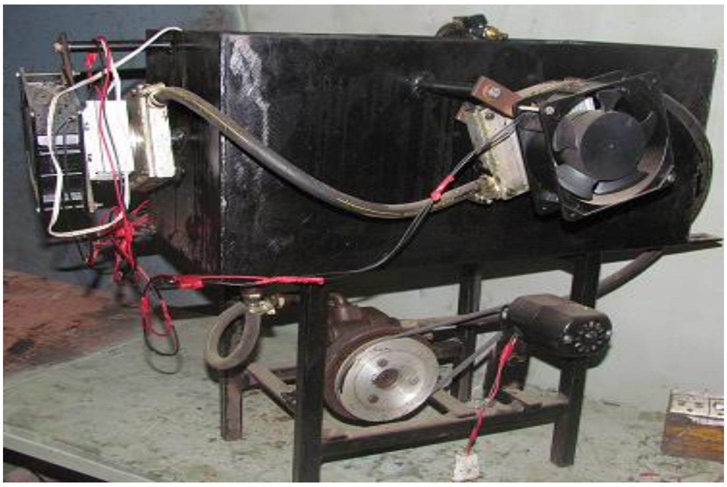

Fig. 2 – Constructional details of the model.

The equipments which are used in the experimental setup are motor, belt drive, cooling model, control valve, heat pipe, oil tank, frame, etc.

A radial blower is a 12-volt DC blower that takes cold air into the axial system and releases it to the radial side. This cold air is then directed to the fins installed in three heat pipe modules. The oil cooler picks up the hot oil with the help of a hydraulic pump while the cold oil from the oil cooler is pumped into the oil tank. The oil cooler can be installed outside the oil tank system thus ensuring free-flowing pollution as the oil tank closes. Improved heat pumps run on a hydraulic cooling system using three heat-connected heat exchanger modules and the exhaust oil from each phase is returned to the oil tank after it has cooled.

5. TESTING EQUIPMENT:-

a) Thermometer / Digital Temperature Indicator:-

Specification:-

Theory - Temperature Sensor

Color – Silver

Accuracy - ±1°C

Temperature range - -9.9°C~+99.9°C

b) Measurement beaker:-

These containers are practically analogous with 'science' itself, are used to accommodate and measure liquids.

c) Stopwatch:–

To measure the amount of time that vanishes between its activation and deactivation, a stopwatch is used.

d) Oil:-

To carry out the experiment the SAE20W50 oil was considered.

- **The Procedure of Trial:-**

Heat oil in the tank with the help of the heater up to desired temperature (say 90^{0}C). Note hot oil inlet temperature (Thi). Open valve partially …Collect oil in the beaker (50 ml). Estimate the viewing time at the stop required to fill 100 ml in the beaker. Take hot oil outlet temperature (Tho). Change valve opening to record further readings from the observation table.

6. DESIGN :

CAD model & fluid domain of model:-

In the design section, the fig. 3 & 4 shows the CAD model of fins & fluid domain.

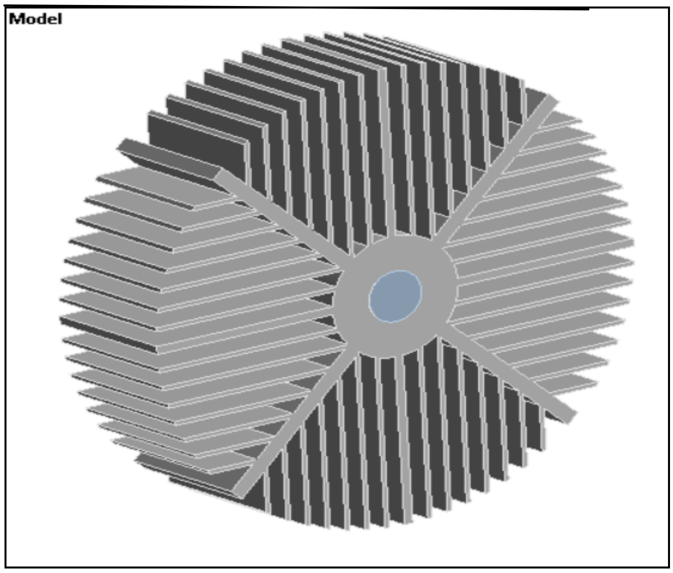

Fig. 3 - CAD model of a fin. (Fin geometry)

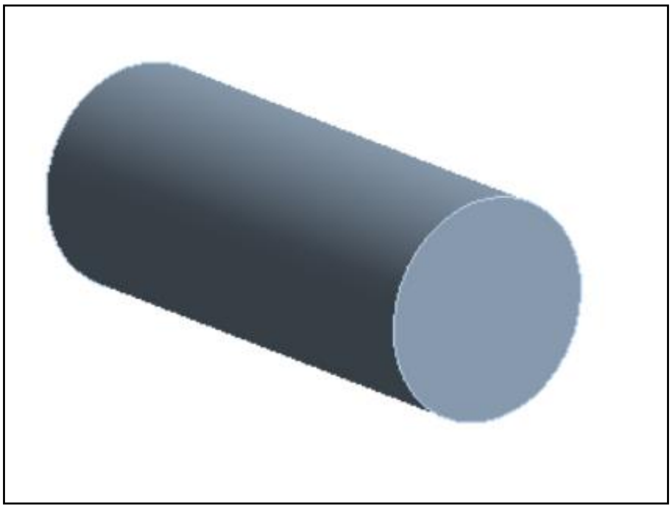

Fig. 4 – Fluid domain

Meshing model:-

In fig. 5 meshing model is shown.

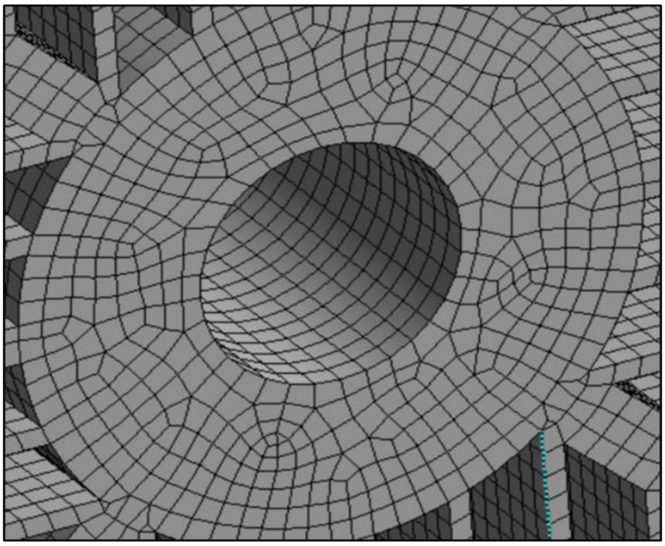

Fig. 5 – Meshing of model

Assembly model :-

In fig. 6 Assembly of the experimental model is shown by the assembling of components like the cooling model with base block, cooling model top plate, heat pipe & cooling fins, etc.

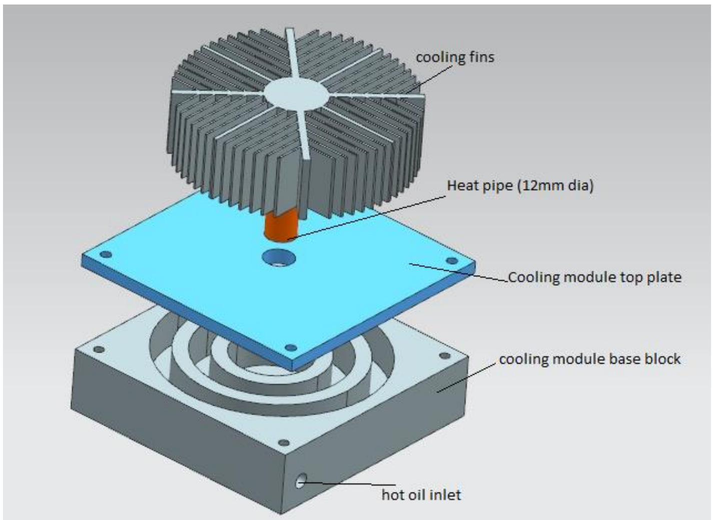

Fig. 6 – Assembly of the cooling model

7. RESULTS :

Table1 - Mass flow rate of hot oil

No.	Volume in Beaker (ml)	Time (Sec)	Mass Flow Rate (Kg/sec)
1	100	38	0.00223
2	100	32	0.00265
3	100	28	0.00302
4	100	24	0.00353
5	100	20	0.00424

Table 2 - Result table of various Parameters.

Hot oil Inlet temp (Thi)	Hot oil Outlet temp (Tho)	Cold air Inlet temp (Tci)	Cold air Outlet temp (Tco)	LMTD	Effectiveness	Overall HTC W/m² K
81	76	30	31.5	47.72	0.09	3.93
80	68.4	30.5	32.5	42.51	0.23	6.36
80.5	61.3	31	31.3	39.28	0.38	4.44
80	57.5	30	33.2	36.17	0.45	22.18

79.5	51.2	30.5	34.8	30.84	0.57	35.51
79	49.6	31	35.4	29.91	0.62	46.68

8. ANALYSIS :-

Fig. 7 shows the fluid that enters the fins & fig. 8 shows the fluid that exits from the fins.

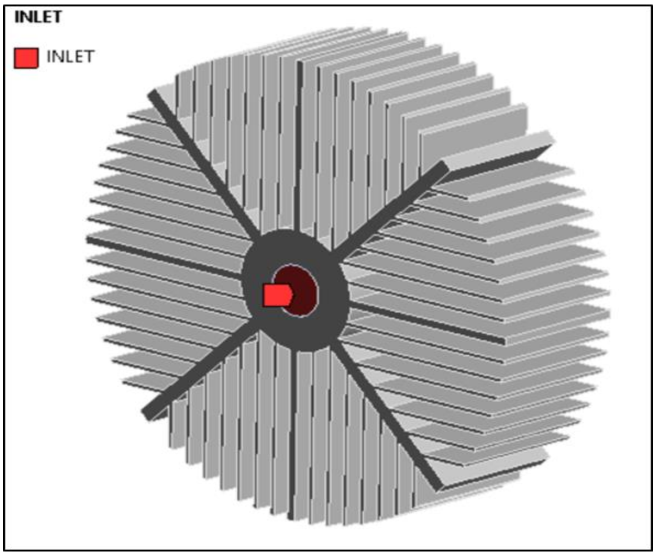

Fig. 7 – Fluid inlet surface

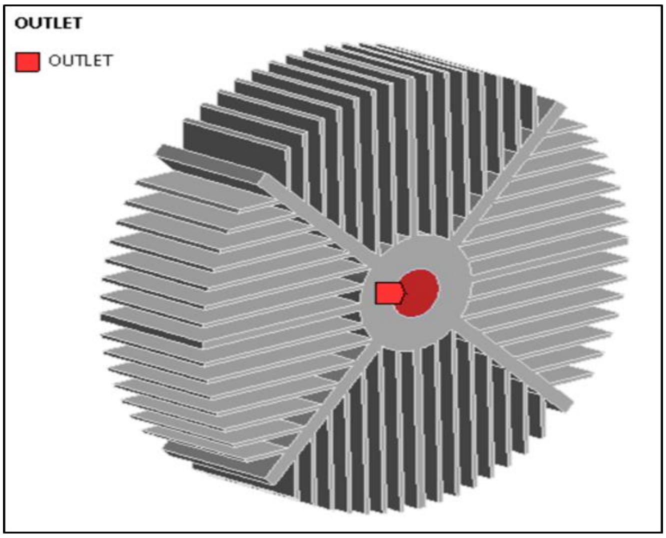

Fig. 8 - Fluid outlet surface

Fig. 9 shows a temperature contour regarding a temperature of 81°C.
Fig. 10 shows a temperature contour regarding a temperature of 80.5°C.
Fig. 11 shows a temperature contour regarding a temperature of 79.5°C.

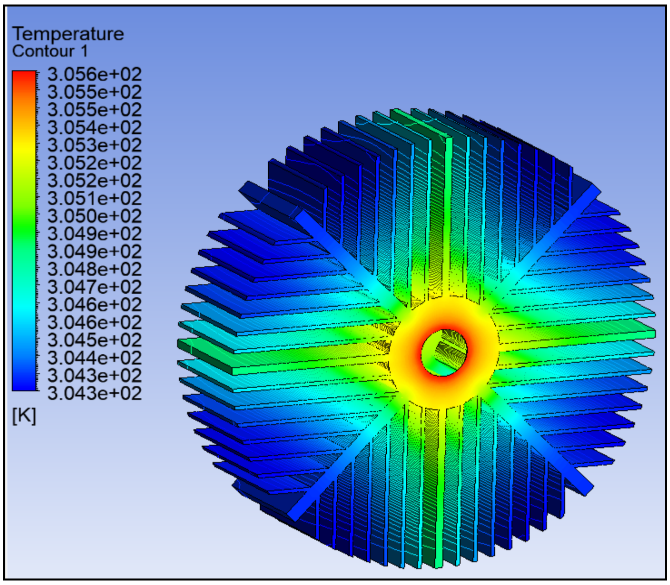

Fig. 9 – Temperature contour of 81°C

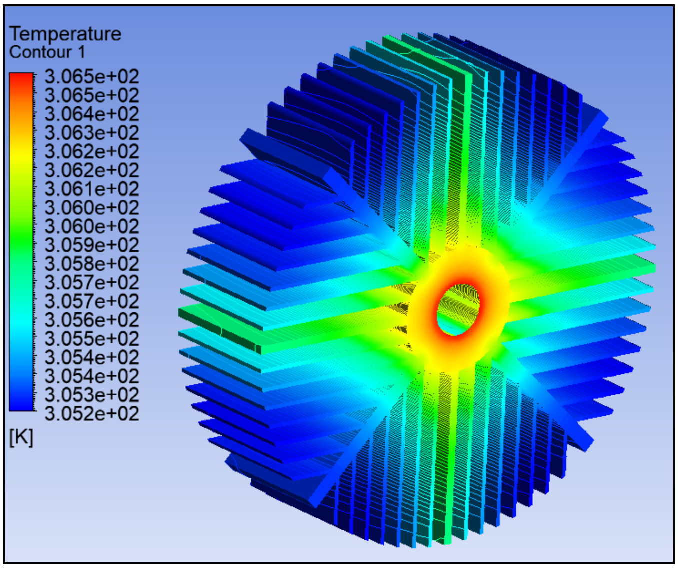

Fig. 10 – Temperature contour of 80.5°C

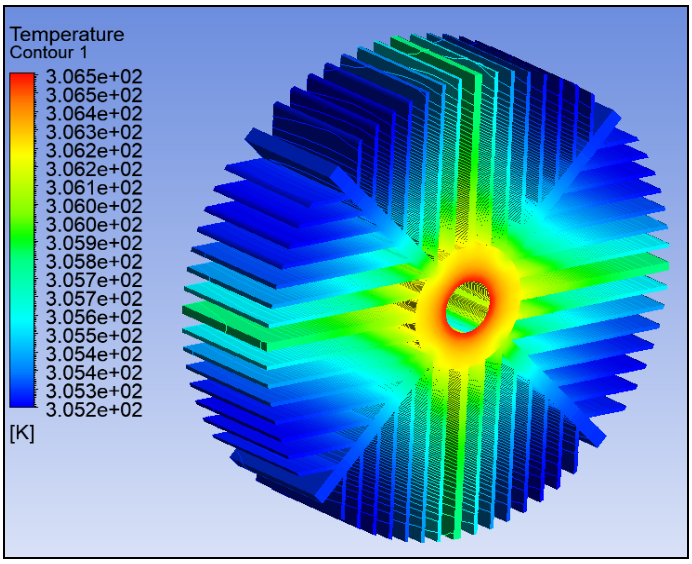

Fig. 11 – Temperature contour of 79.5°C

9. CFD RESULTS :-

Table 3 – CFD results of inlet & outlet temperatures

SR. NO.	Thi °C	Tho °C	Tci °C	Tco °C
1	81	75	30	32
2	80.5	62	31	33
3	79.5	52	30.5	33

Table 4 – Comparison with experimental testing of outlet temperatures

SR. NO.	Tho °C for FEA	Tho °C for Experimental	Tco °C for FEA	Tco °C for Experimental
1	75	**76**	32	**31.5**
2	62	**61.3**	33	**31.3**
3	52	**51.2**	33	**34.8**

Table 5 – Comparison of LMTD, Effectiveness & Overall HTC

SR .NO.	LMTD		EFFECTIVENESS	
	Analysis	Experimental	Analysis	Experimental
1	47.01	**47.62**	0.11	**0.09**
2	38.66	**39.28**	0.37	**0.387**
3	28.06	**30.84**	0.56	**0.577**

SR NO	OVERALL HTC	
	Analysis	Experimental
1	3.98	**3.93**
2	4.51	**4.44**
3	39.02	**35.51**

Formulae:-

LMTD calculation:-

$$\Delta T_{lm} = \Delta T_1 - \Delta T_2 / \ln(\Delta T_1/\Delta T_2)$$

Where,

ΔT_1 = Hot oil inlet temperature (Thi) °C – Cold air outlet temperature (Tco) °C.

ΔT_2 = Hot oil outlet temperature (Tho) °C – Cold air inlet temperature (Tci) °C.

Effectiveness calculation:-

$$\varepsilon = q / q_{max}$$

Where,

Effectiveness (ε) is the ratio of actual heat transfer in a heat exchanger (q) to the maximum possible heat transfer (q_{max}).

Overall HTC calculation:-

$$U = q / A.\Delta T_{lm}$$

Where,

Overall heat transfer coefficient expresses the total resistance experienced as the heat is transferred between oil and air. The overall heat transfer coefficient (U) is calculated by dividing the heat flux (q/A) by the temperature difference between the oil and air (ΔTlm) where heat is being transferred.

Graphs:-

From the result table data, the followings graphs are drawn-

In chart 1 (Log Mean Temperature Difference. LMTD appears to decrease with increasing oil flow rate, so the very low flow may lead to better LMTD as it is provided that the oil comes in contact with the heat pipe.

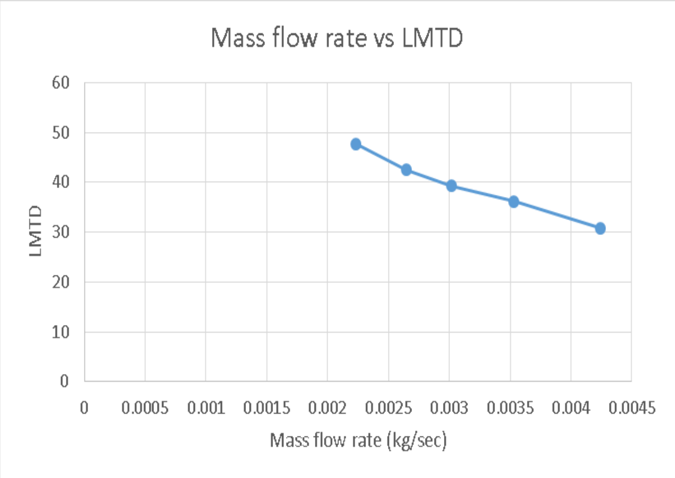

Chart 1 - Graph of Mass flow rate Vs LMTD.

In chart 2, the effectiveness of the heat exchanger raises slightly with increasing oil flow rate and this is due to the effect of increased heat dissipation heat exchanger which increases with increasing mass flow rate.

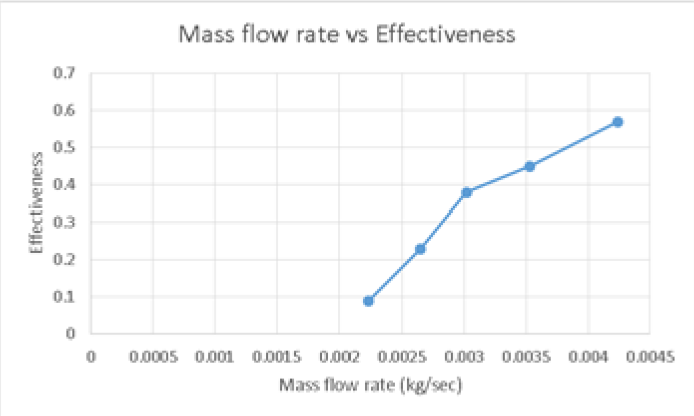

Chart 2 - Graph of Mass flow rate Vs Effectiveness.

In chart 3, the overall HTC is first increases slightly as the mass flow rate increases, at some value of mass flow rate HTC increases are negligible. But after that mass flow rate value 0.003028 overall HTC is increasing rapidly.

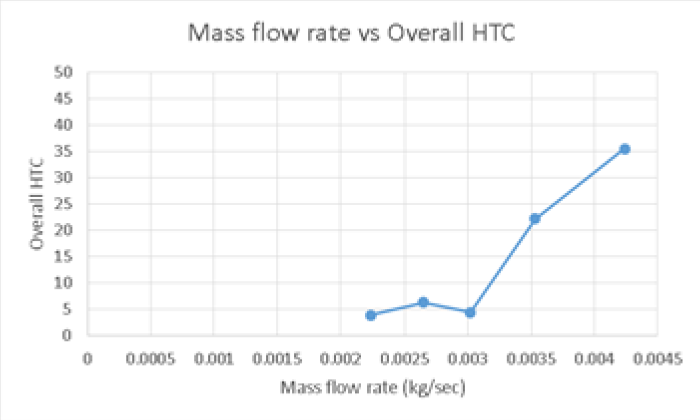

Chart 3 - Graph of Mass flow rate Vs Heat transfer coefficient.

10. CONCLUSION:-

Efficiency is slowly increasing with increasing mass flow rate. As the flow rate increases, the overall heat transfer rate increases. LMTD appears to be declining with an increase in oil flow rates.

A simple, compatible, highly cost-effective, device will be developed, so new tower heat pump technology will be studied. This project will provide the industry with a new tool for solving heat problems in many machines in many systems.

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