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Design and Analysis of Hydraulic Oil Cooler by Application of Heat Pipe

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Abstract— Heat pipe is an essentially passive heat transfer device having high thermal conductivity. In hydraulic power pack use of traditional shell and tube heat exchanger would require lot of space, more power and maintenance cost. So heat pipe device is easily implemented for cooling of hydraulic oil. The heat pipe equipped hydraulic oil cooler uses a heat pipe module comprises of aluminium base block with oil channels machined on it. From hot oil chamber hot oil is passed through each modules of heat pipe. The hot oil passed through evaporator end transferring heat to condenser end. Heat transfer takes place by alternate evaporation and condensation of working fluid inside it. The condenser section of heat pipe is fitted with radial finned structure exposed to air to improve heat transfer rate. Ambient air is drawn over the fins using blower so that the fluid condensed and returns to heat source to repeat the process. In this hydraulic oil cooler heat is removed from hot oil to surrounding air using heat pipes and fins. The objective of the present experimental set up is to enhance the heat transfer of hydraulic oil using heat pipe. The study shows the heat pipe developments for cooling of oil for various applications like power pack, chemical industries etc.

Keywords— **Condensation, Evaporation, Fins, Heat pipes.**

I. INTRODUCTION

A heat pipe is a heat transfer device with an extremely high effective thermal conductivity. The heat pipe has its simple configuration is like a cylindrical vessel with the internal walls lined with a capillary structure or wick that is saturated with a working fluid. When the heat is input at the evaporator section, fluid vaporizes, this creates a pressure gradient in the pipe. This pressure gradient forces the vapour to flow along the pipe to a cooler section where it condenses giving up its latent heat of vaporization. The working fluid is then returned to the evaporator by the capillary forces developed in the wick structure. All heat pipes have an evaporator and condenser section where the working fluid evaporates and condenses, respectively. Heat pipes can be designed to operate over a wide range of temperatures from cryogenic applications utilizing titanium alloy/nitrogen heat pipes, to high temperature applications using tungsten/silver heat pipes.Applications of heat pipe for cooling purpose is widely available. Heat pipe provided with cooling fins to enlarge its contact surface with surrounding medium. A heat pipe with cooling fin is generally termed as a heat pipe cooler.

II. LITERATURE SURVEY

There are a lot of studies on heat pipe and working fluid inside heat pipe Heat pipe is a passive cooling device with high thermal conductivity. Heat pipe is most reliable, efficient in heat transfer, low cost, and high performance cooling elements [1].Applying the heat pipe methodology for cooling normally integrates with cooling fin to enlarge its contact surface with cooling medium. A heat pipe integrated with cooling fin is generally named as a heat pipe cooler. Nowadays, cooling efficiency cannot reach a specified value, which is the main question of a heat pipe cooler. Most of studies on the heat pipe cooler ignored the considerations of the changed heat transfer property inside the heat pipe and investigated only the Integration structure of heat pipe cooler [2-5].Experimental studies on design and fabrication of coaxial dual-pipe heat pipe in connection with cooling water and cooling fin for enhancing the heat transfer property is carried out. The heat pipe is influenced by the outside cooling apparatuses is also considered.The coaxial dual-pipe heat pipe cooler has developed the adiabatic section and increased the effective cooling length of the heat pipe, which will further increase cooling power of the heat pipe cooler [6].Heat pipe is an efficient heat transfer device for maximum heat transfer. Ansys-based FEM models have been developed by Q. Wang,Y. Cao, and R. Wangfor heat pipe cooled piston crown. This numerical results are compared with the experimental measurements. The effective thermal conductance of the annular heat pipe was found to be about 3980 W/m-°C, about 240 times that of the crown material [7]. The concept of heat pipe has also used in hydraulic motor pump for improving heat dissipation. The heat pipe radiator model is developed by YonglingFula, Meng Zhang, HaitaoQilb, Gaocheng An [8]. The obtained results Temperature distribution are simulating by using ANSYS software. The result shows that the heat generated is difficult to transfer only through natural cooling. The average oil temperature is found to be 150.08^0C [8].When the heat pipe radiator model is used, the average oil temperature is found as 73.844 ^{0}C.It shows that the heat pipe radiator used in the hydraulic motor pump can work in an appropriate range. It can greatly reduce the temperature of the oil in hydraulic motor pump. This makes the oil in the hydraulic motor pump at a low level and also helps inreducing the temperature gradient.C. R. Kamthane, P. M. Khanwalkar has developed hydraulic oil cooler using the heat pipe cores that have a shroud with fins and other brackets and braces to secure the components into the reservoir. The study showed that the modules of heat pipe were tested to investigate the characteristics of heat pipe.Since the model is developed for oil cooling, tests were carried out over a temperature difference of 45℃ to 80℃ of inlet and outlet of oil. Heat dissipated by single module is found near about200 watt, and with natural convection it will be 120 watt [9].

III. PROBLEM DEFINATION

Generally hydraulic fluid temperatures above 180°F (82°C) damage most seal compounds and accelerate degradation of the oil. The operation of any hydraulic system at temperatures above 180°F should be avoided, fluid temperature is too high when viscosity falls below the optimum value for the hydraulic system’s components. This can occur well below 180°F, depending on the fluid’s viscosity grade.To maintained stable fluid temperature of hydraulic system its capacity to dissipate heat must exceed its heat load preventing the system from overheating. There are two ways to solve overheating problems in hydraulic systems either decrease heat load or increase heat dissipation of oil. Hydraulic systems dissipate heat of oil through the reservoir. Therefore, check the reservoir fluid level and if level is low, fill to the correct level. Also avoid any obstructions to air flow around the reservoir, such as a build-up of dirt. The ability of the heat exchanger to dissipate heat is dependent on the flow-rate and temperature of both the hydraulic fluid and the cooling air or water circulating through the exchanger. So there is need of such heat exchanger which can dissipate maximum heat compared to conventional system. Dissipating maximum heat cools oil which improves its viscosity. As the viscosity is more the pumping power require for oil will also be less this is an advantage of efficient oil cooler.

IVDESIGN METHODOLOGY

A. *Input Data:*

Oil Grade = SAE 20 W 40
Specific heat of oil = 1.6987 kJ/kg ^{0}C
Oil flow rate = 0.028 Kg/s
Rated Oil pressure for system = 20 bars
Mass in kg/sec = (flow rate in Kg/s) X (density in Kg/liter)
= 0.0047 X 0.896 kg/liter
= 0.00421 Kg/s
Heat Generated in system = p (Pa) × Q (m3/s))/1000
$= (2\times10^6 \times 2.8\ X10^{-5}) \times/1000$
= 0.056 kW

So based on the above calculations heat generated in the system is calculated. This amount of heat must be delivered into atmosphere. For this heat load suitable heat pipe is selected from standard chart.

B. *Selection of Heat pipe:*

TABLE I
MAXIMUM WATTS AT DIFFERENT TEMPERATURES

DIAMETER	40^{0}C	60^{0}C
32 mm	15 WATT	18 WATT

C. *Hydraulic Pump*

Hydraulic Pump = Enerpac - Electric - 0.5HP
Electrically powered, 110/115V
Oil flow at full pressure = 20 (in³/min)

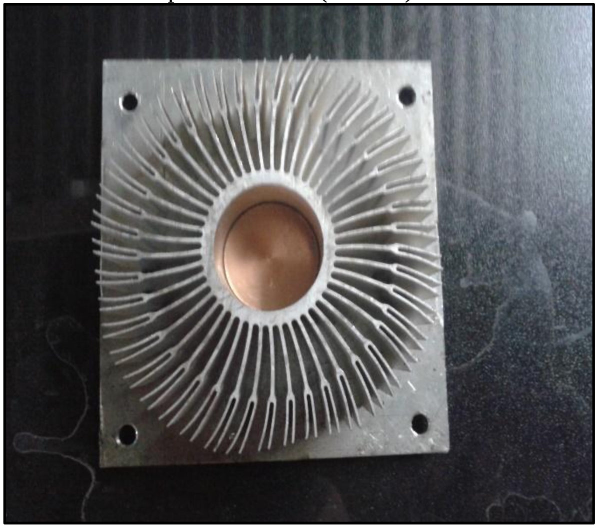

Fig. 1 Standard Heat Pipe

Above figure show the heat pipe selected for given heat load. Heat pipe of following specification is selected.

Diameter = 32 mm
Length = 12 mm long
Evaporator length = 6 mm
Condenser length = 6 mm
Type: Short cylindrical heat pipe
Material: Copper
Working fluid: Water
Wick structure: Sintered copper

The above heat pipe can transfer heat up to 18 watts effectively. So three heat pipes are capable of for a given heat load are used in experimental set up.

D. *Oil Tank*

Fig. 2 Oil tank divided in two chambers

Material used: Mild Steel
Height = 150 mm
Length = 350 mm
Width = 170 mm

E. *Heat pipe Module*

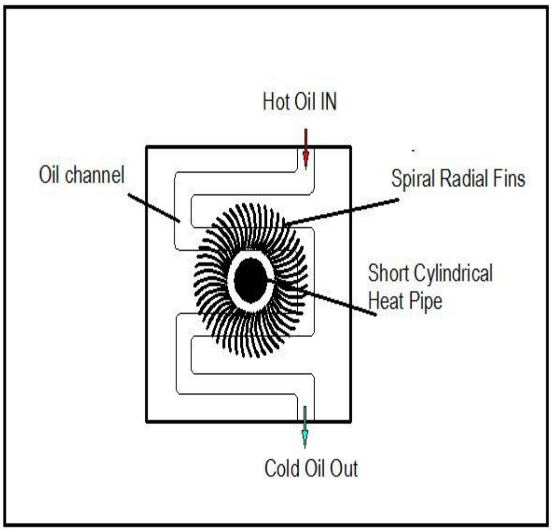

Fig.3 Heat Pipe Module

The heat pipe module contains block made up of aluminum in which oil channels and sealed with a top plate as shown in figure. The heat pipeis press fitted in the cavity of the aluminum block. Spiral fins are attached to the condenser section of heat pipe to enhance the heat transfer as shown.

V. EXPERIMENTAL SET UP

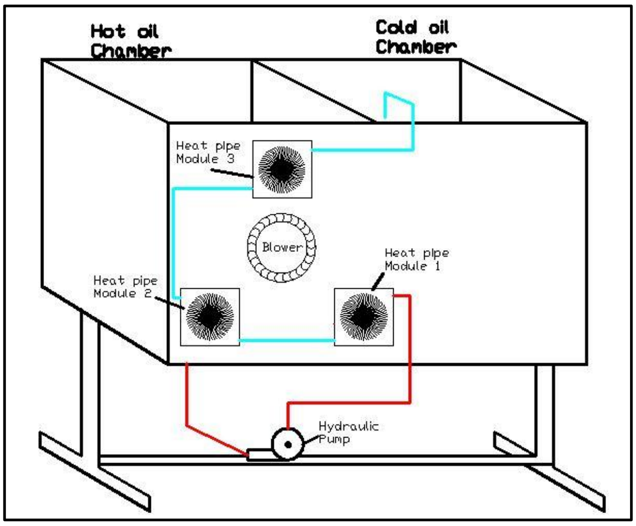

Fig.4 Experimental set up

The above set up consist of tank made up of mild steel divided into two chambers, hot and cold oil chambers as shown. Hydraulic pump of 0.5 HP is circulating oil through three modules of heat pipe. The oil is heated using heater coil. The oil is in contact evaporator section of pipe and heat from hot oil is transferred through working fluid of heat pipe. Hot oil flows from module 1 to module 3 as shown in above figure. The cold oil is collected in cold chamber. The radial blower is fitted centrally which forces air over the fins. Because of forced convection heat transfer rate increases. The cold oil is collected in a beaker and time is noted to measure oil flow rate. Once the cold oil temperature is known the heat transferred through the oil is calculated using relations,

$$Q = m \text{ X } Cp \text{ X } (T_h\text{-}T_c)$$

Where,

Q = heat is transferred from the system (KJ/s)
M = mass flow rate (kg/sec)
Cp = Specific heat of oil in kJ/kg ^{0}C.
(Th-Tc) = Temperature of hot oil at inlet and cold oil at outlet of heat pipe module

VI. RESULTS AND DISCUSSION

The above heat pipe can transfer heat up to 85 watts effectively at 800C. Using three heat pipes are capable of for a heat load of 255 watts which is more than theoretical heat load. The followings are the various flow rates of oil and air that are used for calculations.

TABLE II

DIFFERENT FLOW RATES OF AIR FOR FLOW RATES OF OIL

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Sr. No.	Mass Flow of hot oil (Kg/Sec)	Mass Flow of cold air (Kg/Sec)
1	0.00140	0.0280
2	0.00158	0.0330
3	0.00156	0.0340
4	0.00155	0.0307
5	0.00149	0.0312

From the experimental study presented in paper the following results are obtained.

TABLE NO.III

OBTAINED FINAL RESULTS FOR GIVEN FLOW RATES OF OIL.

Sr. No	**Mass Flow of Hot oil (Kg/Sec)**	**LMTD (θm)**	**Overall heat transfer coefficient *U* (W /m^2 ° K)**	**Capacity Ratio**	**Effectiveness (ε)**	**Heat Transfer rate Q (w)**
1	0.0048	29.28	247.73	0.307	0.645	326.41
2	0.0065	29.65	364.40	0.325	0.686	486.20
3	0.0058	29.75	299.33	0.329	0.655	396.02
4	0.006	29.90	352.25	0.349	0.660	467.61
5	0.0089	30.59	494.60	0.362	0.725	680.84

A. Analytical Results of Thermal Analysis of Spiral Fins.

The analytical results are presented as shown in figureThemodel of heat pipe module with spiral fins is developed in ANSYS version R 14.5. The thermal analysis of spiral fins is carried out and obtained results are as follows:

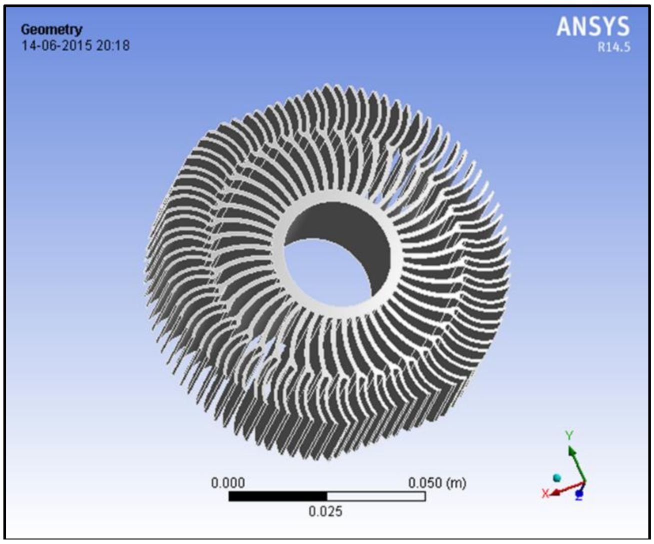

Fig.5 Spiral fin model

Detailed Mass Properties
Analysis calculated using accuracy of 0.990000000
Information Units kg - mm
Density = 0.000002660
Volume = 45749.346346060
Area = 106970.325514622

Mass = 0.121693261

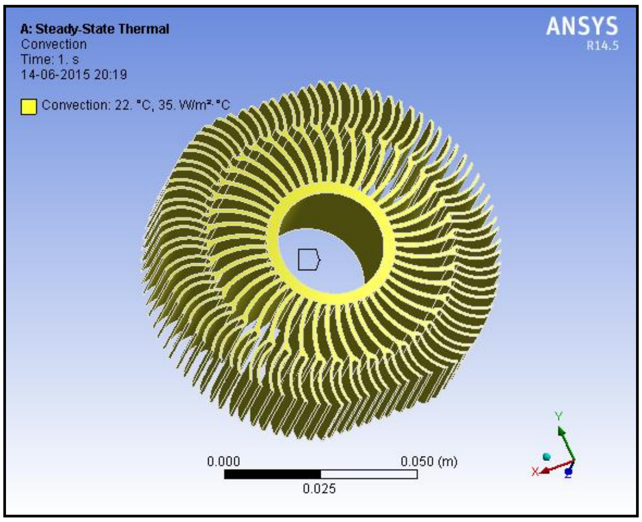

Fig.6 Thermal distribution of heat flux

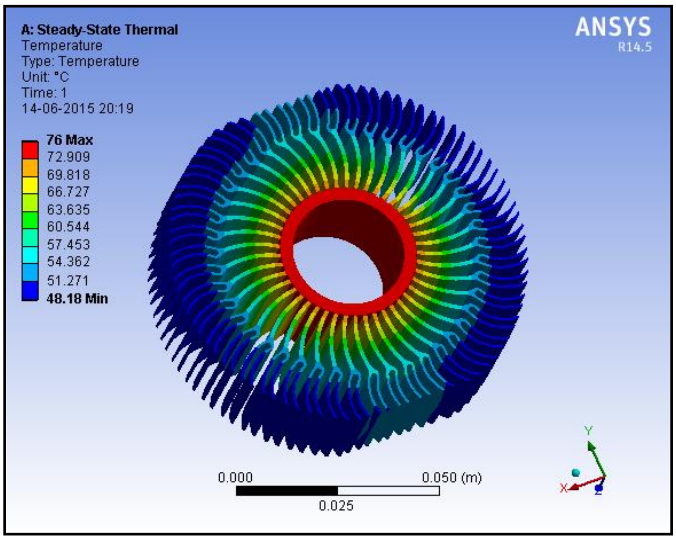

Fig 7. Temperature behaviour of spiral fins

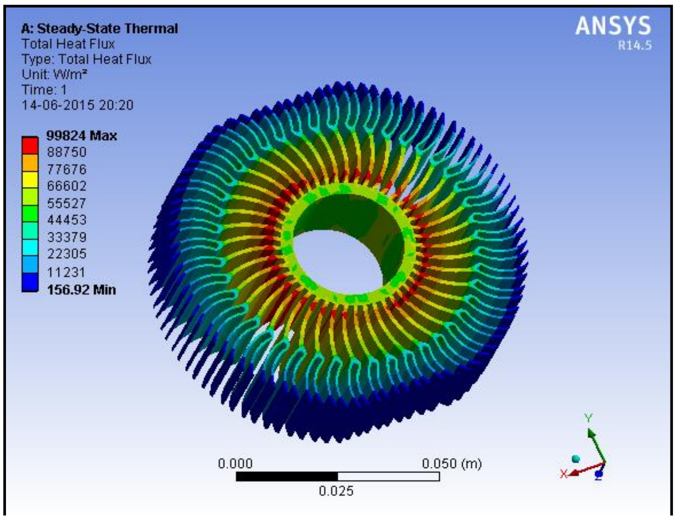

Fig.8 Rate of Heat Energy Transfer through Fins

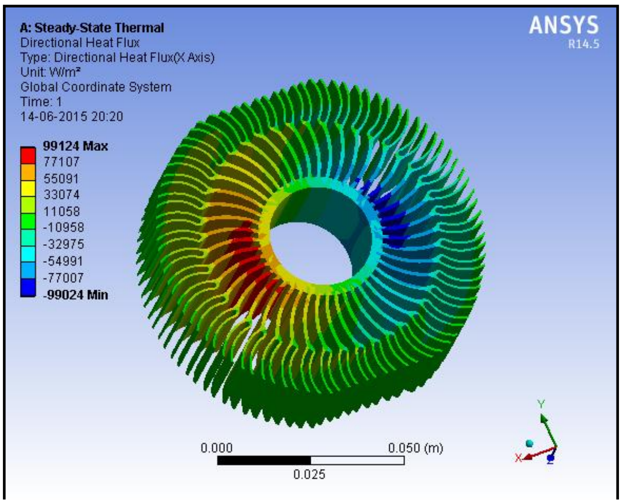

Fig.9 Rate of Heat flux Transfer through Fins

The maximum heat transferred through the spiral fins is 156.20 W/m^2 which covers the maximum fins surface.Theorotcally the heat generated is 56 watts which is less hence design is safe.

B. Discussion.

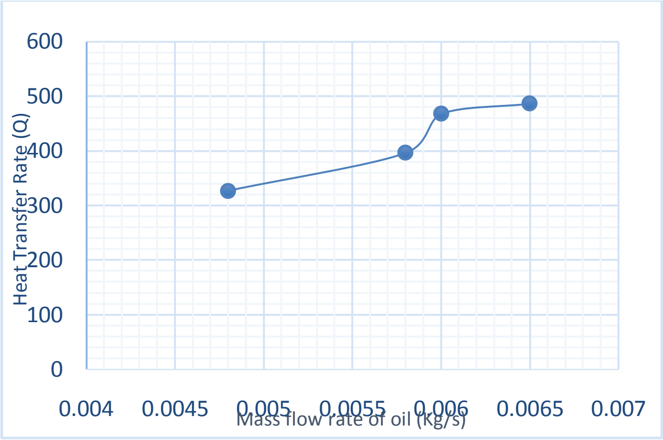

Fig. No 10. Mass flow rate vs. heat transfer rate

The relationship of above graph shows that increase in mass flow rate of oil results in increase in heat transfer rate. The nature of graph is linear for flow rate range from 0.0048 Kg/s to 0.0058 Kg/s. After that point because of sudden increase in mass flow rate the nature of graph diverts.

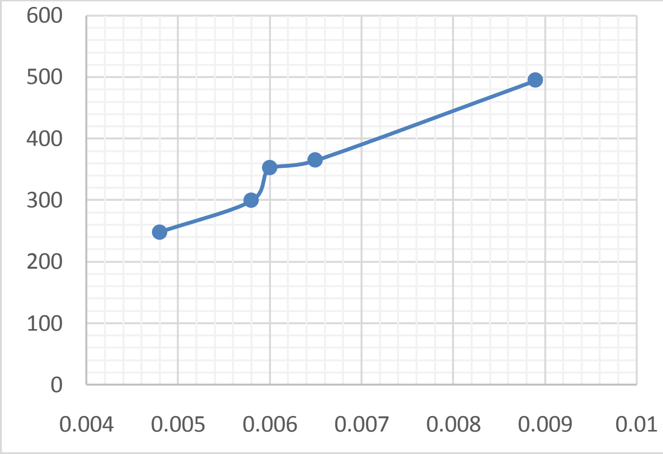

Fig. No 11. Mass flow rate vs. overall heat transfer coefficient.

Fig, no 11 shows that as the mass flow rate increases the overall heat transfer rate (U) increases. The heat transfer coefficient is maximum i.e. 494.60 W /m2° K at mass flow rate of 0.0089 Kg/s. The nature of graph is linear up to flow rate of 0.0058 Kg/s. It get diverted at this point and increases sudden up to flow rate of 0.0060 Kg/s. From this point graph shows slightly reducing nature up to flow rate of 0.0065 Kg/s and again graph shows linear nature.

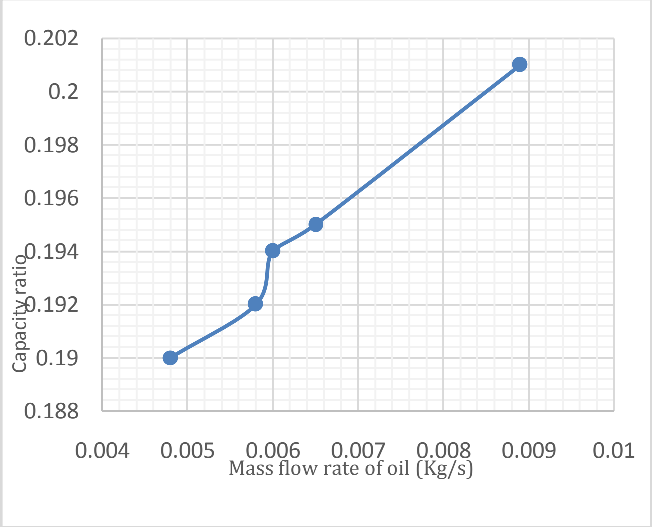

Fig. No 12. Mass flow rate Vs. Capacity ratio

Fig no. 12 shows the effect of mass flow rate on capacity ratio, from graph it is found that capacity ratio is increasing with the mass flow rate. If capacity ratio is more that means heat capacity rate of cold fluid is less. The low capacity rate for cold fluid is desirable because it shows that there is possibility of transfer more heat. The nature of above graph is linear at starting for the flow rate range of 0.0048 Kg/s to 0.0058 Kg/s. The graph deviates at that point and continues up to 0.0065 Kg/s. From this point the graph again behaves as a linear nature.

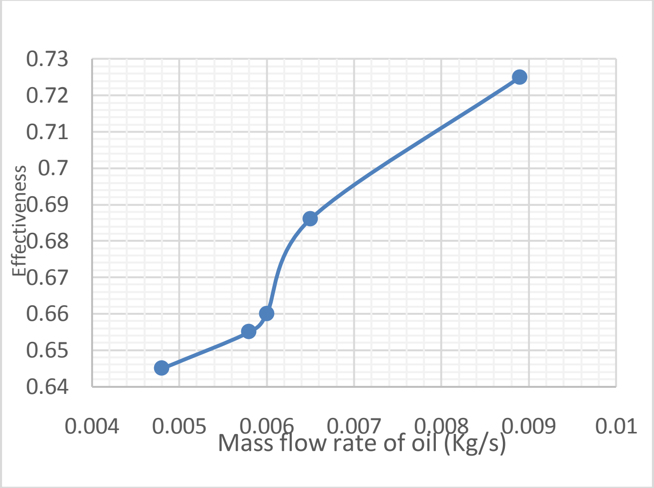

Fig. No 13. Mass flow rate Vs. Effectiveness

The extended surface design of heat pipe has many fins attached on the condenser section. This fins provide more surface area and improves the heat transfer coefficient thereby increasing the effectiveness of oil cooler.

VII. CONCLUSIONS

- It is found that overall heat transfer coefficient increases with the increase in mass flow rate. For maximum mass flow rate (0.0089 Kg/s) it is found to be increased up to 494.60 W/m2 ° K which more than theoretical heat load hence system is safe and will not overheat.
- The capacity ratio and effectiveness is increased with the mass flow rates. This shows that the existing cooler is more efficient at higher flow rates. The highest effectiveness is found as 0.725.
- Thermal Analysis on Spiral fins of heat pipe module shows the maximum amount of heat transfer rate. The total heat flux is up to 80 Kw/m2 which is more than heat generation in the system.

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