Performance Evaluation of Heat Pipe Oil Cooler in Hydraulic System

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Abstract— Overheating is most common problem with hydraulic equipment. Heating of hydraulic fluid in hydraulic system during operation is caused by inefficiencies. Inefficiencies are due to loss of input power, which is converted to heat. So to achieve stable fluid temperature, a hydraulic system capacity to dissipate heat must exceed its heat load. In current market, various types of heat exchanger are used to avoid overheating, but they require a lot of space, extra power and investment is required for the cooling water circuit and maintenance of the heat exchanger. Therefore oil coolers are needed to design specifically for mobile hydraulic applications where high performance and efficiency are required and physical size is minimized to allow easy installation. Typical applications include mobile cranes, concrete mixers and pump trucks, road paving machines & transmission cooling. The oil cooler use a combination of high performance cooling elements and hydraulic motors to give long trouble free operation in mobile hydraulic applications. The compact design allows the coolers to fit most equipment and provide the highest cooling performance in heat dissipation whilst minimizing space required. The paper focuses on the design and performance analysis of a single unit of oil cooler, which consist of base module aluminium block with concentric channels for oil passage moving about a heat pipe evaporator section which then dissipates the heat to a rectangular fin structure assisted by forced air cooling. The paper discusses the selection of heat pipe for the application of oil cooling and performance of the heat exchanger in terms of LMTD, effectiveness and overall heat transfer coefficient.

***Keywords*:** Heat pipe, Reservoir, Boiling, Pump, Blower.
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I. INTRODUCTION

A heat pipe is device which combines the principles of thermal conductivity and phase transition to transfer heat from one solid interface to other solid interface. Heat pipe make the use of highly efficient method of heat transport process which combines evaporation and condensation mode of heat transfer. Heat pipe are considered as superconductor because they can transfer heat in large amount over a large distances with small temperature difference between source and sink. Heating of hydraulic fluid in operation is caused by inefficiencies. Inefficiencies result in losses of input power, which are converted to heat. A hydraulic system heat load is equal to the total power lost (PL) through inefficiencies and can be expressed as:
$PL_{total}=PL_{pump}+ PL_{valves}+ PL_{plumbing}+ PL_{actuators}$. If the total input power lost to heat is greater than the heat dissipated, the hydraulic system will eventually overheat. Installed cooling capacity typically ranges between 25 and 40 percent of input power, depending on the type of hydraulic system. To achieve stable fluid temperature, a hydraulic system capacity to dissipate heat must exceed its heat load. Due to overheating many problem occurred as follows:

1. Decrease in oil viscosity increases the power consumption of the power pack unit.
2. Gumming tendency of oil at high temperatures leads to depleting oil lubricating and power transmission capacities thus the oil needs to be replaced frequently.
3. Maintenance cost increases.
4. Life of system components reduced due to overheating.

The oil air cooler module is a system that uses the excellent heat dissipation properties of heat pipe to extract heat from hot oil about the evaporator section. The passage of oil is taken to be in concentric patterns about the heat pipe making it possible to extract maximum amount of heat. Thus the structure of the heat exchanger unit is as shown above where in the base block is made of aluminium with concentric channels for water that move oil around the heat pipe. The specifications of the base block are 90x 90x 25 mm with the top cover 90x S90x5 mm.

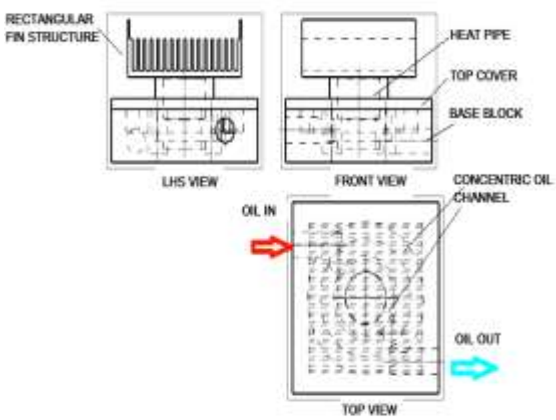


Fig. 1 Three views of fin structure

II. LITERATURE REVIEW

Interest in the heat pipe concept developed rapidly both for space and terrestrial applications, Work was carried out on many working fluids including metals, water, ammonia, acetone, alcohol, nitrogen and helium. At the same time the theory of heat pipe become well understood. Many Heat pipe are strictly called thermo syphon, as they do not possess capillary or other means for transporting liquid internally.

(C. R. Kamthane et al, 2014) performed a study on Development of enhanced cross flow heat pipe hydraulic oil cooler in which they concluded heat pipe is capable to transform more heat in comparison to simple copper rod. By using four module of heat pipe series of tests were performed in order to investigate the characteristics of heat pipe. Since the model is developed for oil cooling, tests were carried out over a temperature difference 45℃ to 80℃ of inlet and outlet of oil. Heat dissipated by single module was near about 200 watt, and with natural convection was 120 watt. By the application of heat pipe cooling of oil is more effective than conventional technique of using simple fan over pipes inside which hot oil is flowing.

(T.MallikharjunaRao, et al.2014) conducted experiment on heat pipes for steam condensation in which they concluded that Heat pipes can be used for steam condensation purpose. Due to the usage of heat pipes, there was considerable reduction in the heat transfer surface area. Hence number of tubes carrying cooling liquid get reduced which results easy of operation and low maintenance problems in Power Plant Condensers.

(B. Orret al. 2015) performed a study on car waste heat recovery systems utilizing thermoelectric generators and heat pipes. In that study they investigated that heat pipe reduces the thermal resistance in between the thermoelectric generator and gases. Also they found that heat pipe reduces pressure losses in gas stream due to the reduced fin surface. Because of using heat pipe design was more flexible and it can be useful for temperature regulation of the thermoelectric generator. The use of heat pipes potentially reduced the thermal resistance and pressure losses in the system as well as temperature regulation of the TEGs and increased design flexibility.

(Chintan D Patel et al, 2012) performed a study on pulsating heat pipe based heat exchanger. In that they understand the thermal performance of PHP based liquid-liquid heat exchanger in terms of heat transfer and development of an analytical model to theoretically predict its effectiveness. In their study they concluded that heat transfer with working fluid filled inside PHP was much higher than dry PHP. For the low values of heat throughput PHP in gravity supported orientation performs better than PHP in anti-gravity. In general, PHP performs belier at the volumetric filling ratio 40% than that of 80%.

(Harshal Gamit, et al. 2015) performed a Experimental investigations on pulsating heat pipe. Various experiments have been carried out in order to check the influence of filling ratio and input heat flux on the performance of the Closed Loop Pulsating Heat Pipe (CLPHP). Water used as working fluid. Inner diameter of the copper tube was 2.15mm. Heat transfer mechanism was a natural convection in condenser section. Experiments were conducted with filling ratio as 40%, 50% and 60%. Heat input varied as 10W, 20W, 30W, 40Wand 50W. The conclusions drawn from research paper was system performs better with lower FR for the same input heat flux, Steady state evaporator temperature was observed to increase with increase in FR for the same heat input values. (Sameer Khandekar et al. , 2004) performed a study on closed and open loop pulsating heat pipe. In this they summarized the complex thermo-hydrodynamics of pulsating Heat Pipes (PHPs), especially suited for thermal management of electronics. They concluded that the technology was very well suited for thermal management of high heat flux electronics. In their study they conclude the result for both closed and open loop heat pipe. From a thermal point of view, CLPHPs wasdevice which lie in between extended surfaces metallic fins and conventional heat pipes.

(Milind A. Wahile, et al. 2011) performed a Testing and analysis of enhanced-cross flow heat pipe hydraulic oil cooler. In that they concluded that heat pipe are effective heat transfer device which had found many application in industry.

(Mr. Ashish A. Wankhede,et al. 2015) performed an experimental application of Heat Pipes in Hydraulic Oil Cooler. In their experiment from observation and calculation they concluded that heat transfer rate of oil is increased reaches up to 0.70 kJ/S for nearly constant mass flow rate. According to them blower helps to transfer heat effectively and the overall heat transfer rate also increased during given flow rate of oil. Finally they concluded that the temperature difference between oil inlet and outlet was decreases which means oil outlet temperature was decreasing for the given flow rate of oil.

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. In this study the modules of heat pipe uses rectangular fins rather than shroud with fins and fluid used in heat pipe is ethylene rather than water. In this way heat pipe model is tested for new fluid and new arrangement of setup. Since the model is developed for oil cooling, tests were carried out over a temperature difference of 45 C to˚80 C of inlet and outlet of oil.

III. PROBLEM DEFINITION

Hydraulic fluid temperatures above 180°F (82°C) damage most seal compounds and accelerate degradation of the oil. The working 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 maintain 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. 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 be less as well as leakage problem is also less which is an advantage of efficient oil cooler.

IV. DESIGN METHODOLOGY

Input Data:
Oil Grade = SAE 20 W 60
Specific heat of oil = =1.7 KJ/KGK
Specific Gravity = 0.915
Mass in kg/sec = Flow rate (Kg/s) X Density (Kg/liter)
Heat Generated in system = p (Pa) × Q (m3/s))/1000
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.

V. SELECTION OF HEAT PIPE

The basic components of heat pipe are as follow:

1) Container
2) Working fluid- Ethylene.
3) Wick structure- Sintered copper.
   Type: Short cylindrical heat pipe
   Case material: Copper
   Outside diameter: 26 mm
   Length: 16 mm
   Evaporator length: 6mm
   Condenser length: 6mm

Heat dissipation ability:

DIAMETER	20^{o}C	30^{o}C
26	37.2WATT	50 WATT

Log mean temperature difference can be calculated by using formula: (For Counter Flow)

$$LMTD = (\Delta 1-\Delta 2) / \ln (\Delta T1/\Delta T2)$$

Where $\Delta 1 = T_{Hot\ in} - T_{Cold\ out}$

$\Delta 2 = T_{Hot\ out} - T_{Cold\ in}$

VI. EXPERIMENTAL SET-UP

The spiral radial heat fins act as heat transfer enhancement as they offer maximum surface area in the given space. The blower is 12 volt DC blower that takes cold air in the system and discharges it in axial direction. This cold air is then directed on to the spiral radial fins mounted on the heat pipe modules. The oil cooler supplies hot oil with help of hydraulic pump where as the cold oil from the oil cooler is discharged back to the oil tank. This set up consist of two tank one has hot oil init while other has cold oil. Hot oil from hot chamber is pumped into heat pipe module assembly as shown. The heat pipe dissipates heat from oil effectively through spiral radial fins. The blower is used to have forced convection resulting increase in heat transfer rate. The cold oil is then drawn out and collected in cold oil chamber.

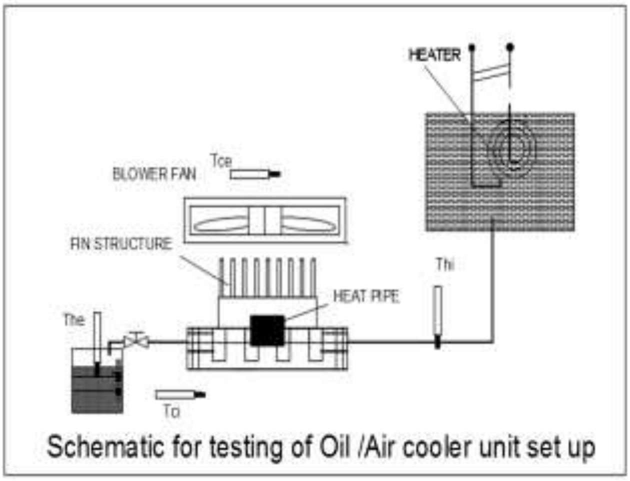


Fig. 1 Block Diagram of Setup

Procedure of trial:

1. First Heat oil in the top tank up to desired temperature.
2. Heat the oil up to given temperature range.
3. Start oil flow from system at a specific flow rate by adjusting electronic speed regulator.
4. Start bower fans.
5. Take mass flow readings for hot oil and also note temperature gradient.
6. Take temperature readings of air.

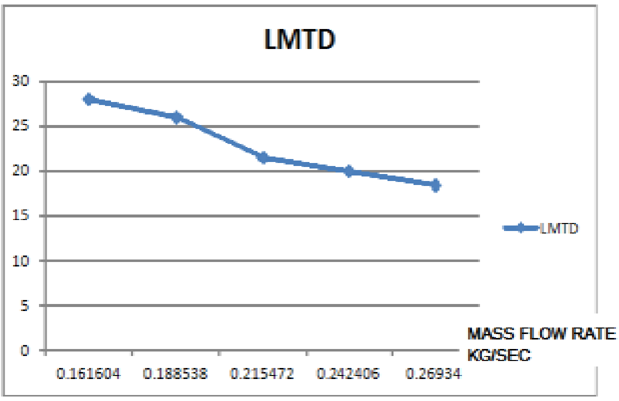
Test & Trial:

Input Data- Oil (Hot Fluid) DATA, Grade : SAE 20 W 60	
Specific Gravity	0.915
Specific Heat	1.7 KJ/KgK, 1 KJ/KgK= 0.2389 kcal/(kg ^{o}C)
Specific of air at (250 to 30 0 C)	1.005 kJ/kg-k

VII. RESULT AND DISCUSSION

With the help of experimental setup various tests are performed with different mass flow rate. For these mass rate various parameter like LMTD, Capacity ratio, Effectiveness, & Overall heat transfer coefficient are calculated and plotted on graph. The graphs are plotted as mass flow rate verses LMTD, Capacity ratio, Effectiveness & Overall heat transfer coefficient. From these tables and graphs we get performance of heat pipe for different mass flow rate. These graphs are as follow:

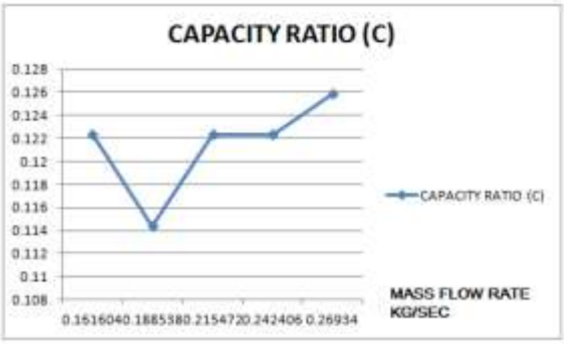
Effect of mass flow rate on LMTD



Graph 1. The LMTD drops with increase in mass flow rate.

It is observed from the graph that LMTD of heat pipe decreases as mass flow rate goes on increases. From graph it is clear that value of LMTD is more for lower mass flow rate and as mass flow rate goes on increasing the LMTD goes on decreasing. Initially for the value of mass flow rate 0.1616Kg/s the LMTD is 27.988 and finally it becomes 18.386 for mass flow rate 026934Kg/s. So there is decrease in LMTD by 34%

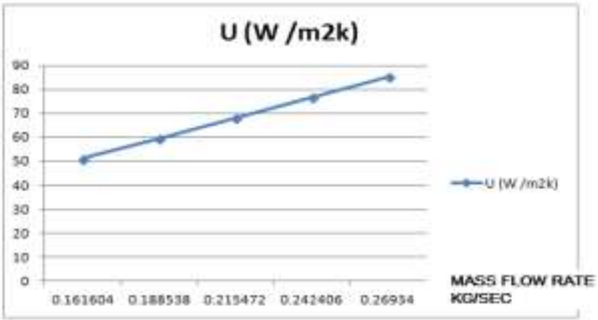
Effect of mass flow rate on Capacity ratio



Graph 2. The Capacity ratio increases with increase in mass flow rate.

From graph it is observed that Capacity ratio increases as the mass flow rate increases. Capacity ratio is nothing but the ratio of two specific heat at constant pressure and other at constant volume. For the mass flow rate 0.1885Kg/s the capacity ratio is 0.1144 and as mass flow rate increases the capacity ratio also goes on increasing and finally for mass flow rate 0.26934Kg/s it becomes 0.12584. From graph we can write that with increasing mass floe rate there is increase in capacity ratio by 10%

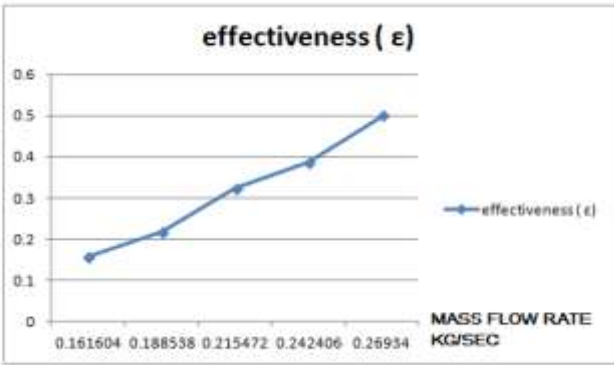
Effect of mass flow rate on Overall heat transfer



Graph 3. Overall heat transfer coefficient Vs Mass flow rate

When there is increase in mass flow rate takes place the overall heat transfer coefficient also increases. It is oblivious that as mass flow rate increases the amount of fluid carrying heat also increases and therefore with increasing mass flow rate there is increase in overall heat transfer coefficient. For mass flow rate 0.1616Kg/sec the overall heat transfer coefficient is 51.1405w/m^{2}k and with increasing mass flow rate it also increases. When mass flow rate is 0.2693Kg/sec then overall heat transfer coefficient is 85.2341w/m^{2}k. so we can write that overall heat transfer coefficient increase by 40%.

Effect of mass flow rate on effectiveness



Graph 4.The effectiveness Vs mass flow rate.

From the graph of mass flow rate versus effectiveness it is clear that as mass flow rate increases the effectiveness also increases. In graph for 0.1616Kg/sec mass flow rate the effectiveness is 0.15625 and it is increasing with increasing mass flow rate. For 0.2693Kg/sec mass flow rate the value of effectiveness is 0.5. It means the value of effectiveness is increase by 2.33.

VIII. CONCLUSIONS

The LMTD decreases as the mass flow rate increases.
The Capacity ratio increases with increase in mass flow rate.
The Overall heat transfer coefficient increases with increase in mass flow rate.
The Overall heat transfer coefficient increases with increase in mass flow rate.
Thus the system exhibit maximum heat transfer at full rated speed of the blower and thereby ensuring 85 watt /m2 k which will avoid the overheating of the hydraulic system

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