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Heat Pipe Oil Cooler Module with Cross Flow Structure for Hydraulic System

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Abstract— Hydraulic equipment suffers with the problem of overheating. Heating hydraulic system during operation is caused by inefficiencies. The loss input power is converted into heat. This heat if not dissipated to atmosphere then system comes under the condition of overheating. In current market, various heat exchangers 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.

Index Terms— Heat pipe, Reservoir, Boiling, Pump, Blower.

1 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:

PLtotal=PLpump+ PLvalves+ PLplumbing+ PLactuators.

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:

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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. Heat pipes have an envelope, a wick, and a working fluid. Heat pipes are designed for very long term operation with no maintenance, so the heat pipe wall and wick must be compatible with the working fluid. Some material/working fluids pairs that appear to be compatible are not. For example, water in an aluminum envelope will develop large amounts of noncondensable gas over a few hours or days, preventing normal operation of the heat pipe.

2 Methodology

2.1 Hydraulic Fluid Temperature

Hydraulic fluid temperatures above 82°C damage most seal compounds and accelerate degradation of the oil. While the operation of any hydraulic system at temperatures above 82°C should be avoided, fluid temperature is too high when viscosity falls below the optimum value for the hydraulic system's

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components. This can occur well below 82°C, depending on the fluid's viscosity grade.

2.2 Heat Pipe Enhanced Cross Flow Hydraulic Oil Cooler

The concept of the heat pipe enhanced cross flow hydraulic cooler is oil to air cooler that uses three heat pipe modules with a axial blower system. The axial blower is computer fan which takes cold air in the system axial and discharges it in axial direction. This cold air is then directed on to the fins mounted on the heat pipe modules. The oil cooler takes in hot oil with help of hydraulic pump whereas the cold oil from the oil cooler is discharged back to the oil tank. The oil cooler can be mounted externally to the oil tank system thereby ensuring contamination free operation as the oil tank is sealed.

This set up consist of tank split in two parts one has hot oil inlet while other has cold oil. Hot oil from hot chamber ipumped into heat pipe module by using gear pump. This hot oil entered into first heat pipe module and gives heat to the evaporator section of heat pipe. Due to heating, fluid inside the heat pipe gets evaporates and moves towards condenser section where it dissipates heat. After dissipation of heat it is converted into liquid and via wick structure due to capillary action again it entered into evaporator section.Condenser section of heat pipe is connected to fin structure which dissipates this heat to air. The heat pipe dissipates heat from oil effectively through straightfins. The axial blower is also used to have forced convectionresulting increase in heat transfer rate. The cold oil is thenentered into second heat pipe module and then after into third module where same process happen. Finally cold oil is drawn out and collected in cold oil chamber

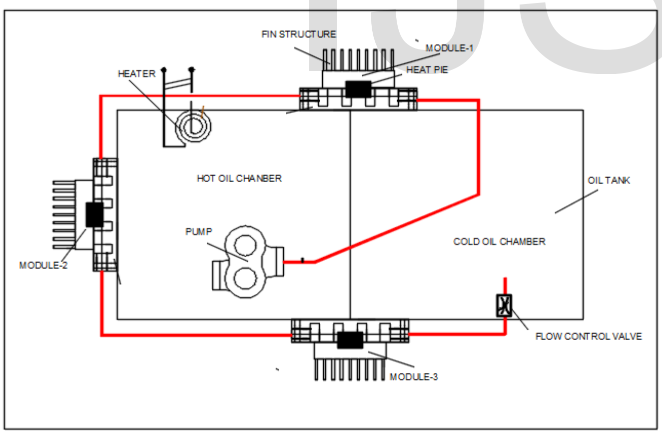

Fig 1 Experimental Setup

The heat pipe module comprises of a base aluminium block with oil channels machined on the top face of the block, and then sealed by top plate as shown in figure 1.4. The heat pipe used to transfer the heat from the hot oil to the fins is press fitted in the cavity of the aluminium block. The heat pipe evaporator section is in direct contact with hot oil whereas the condenser section of the heat pipe is fitted to straight type of fin structure.

The heat pipe used in the module has following specifications:

a) Type: Short cylindrical heat pipe
b) Material: Copper
c) Working fluid: Water
d) Wick structure: Sintered copper

2.3 Single Heat Pipe Module

The heat pipe module contains of a base aluminum block inwhich oil channels machined on the top face of the block asshown in figure 2 and then sealed with a top plate. The heat pipe used to transfer the heat from the hot oil to the fins is press fitted in the cavity of the aluminum block. The axial blower is mounted in front of heat pipe module in such way that it takes air from outside and blows over heat pipe axially.

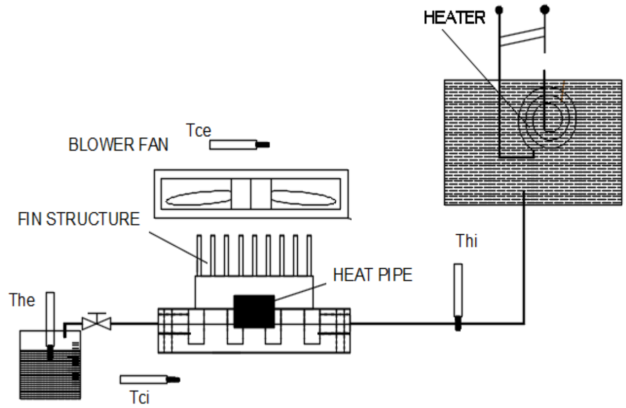

Fig 2 Single Heat Pipe Module

2.4 Design Methodology

Heating of hydraulic fluid in operation is caused by inefficiencies. Inefficiencies result in losses of input power, which are converted toheat. A hydraulic system's 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. So it is required to design the heat transfer equipment in such way that the heat dissipation should be greater than heat developed.

2.4.1 Heat Generated in System

Heat goes into the hydraulic oil at every place in the system where there is pressure loss due to flow of oil without mechanical work being produced. Pressure relief, pressure reducing, and flow control valves are the most common point of heat generators in the system. Hydraulic pumps and motors have a power loss of about 15% of their input power and most of this goes into heat.

2.5 Selection of Heat Pipe

In market various heat pipe are available with maximum watts that can be dissipated for the given temperature range. With increasing temperature range there is increase in dissipation of heat from heat pipe. From various chart heat pipe selected for the given condition is Short cylindrical heat pipe with 32 mm in diameter.

2.5.1 Specification of Heat Pipe

Type = Short Cylindrical Heat pipe
Diameter = 32 mm
Length = 12 mm
Evaporator Length = 6 mm
Condenser Length = 6 mm
Material = Copper
Working Fluid = Water

Wick Structure = Sintered metal powder wick.

2.5.2 Experimental Procedures

1. Heat the oil in hot side of the tank by using heater upto desired temperature, and then shut down the heater.
2. Measure the temperature of oil by using temperature indicator and confirm it is at required level.
3. Start oil flow from system by switching on pump at a specific flow rate by adjusting electronic speed regulator
4. Start blower fans.
5. Take mass flow readings of oil by using beaker and stopwatch. Collect the oil at outlet and measure time for the specific volume of oil.
6. Measure the temperature of hot oil and then temperature of cold oil after drawn out from heat pipe modules by using temperature indicator.
7. Take temperature readings of air before blow on the fins and after blow on the fins.
8. Finally shut down the pump as well as blower fan by switching off the switch button.

3 RESULTS AND DISCUSSIONS

3.1 Effect of Mass Flow Rate on LMTD

It is observed from the graph that LMTD of heat pipe decreases as mass flow rate goes on increases. From above figure 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%.

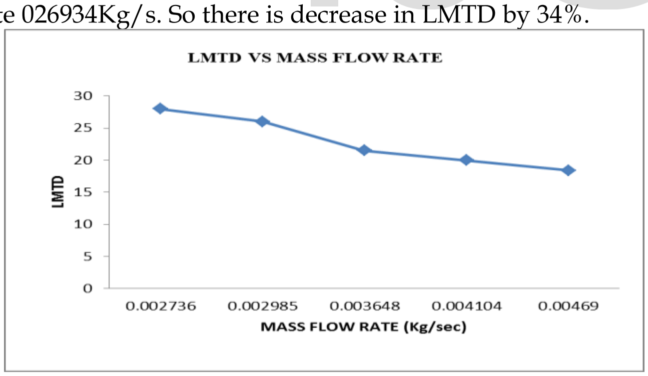

Fig 3 Effect of Mass Flow Rate on LMTD

So to maintain high value of LMTD it is required to maintain low mass flow rate of the flow.

3.2 Effect of Mass Flow Rate on Capacity Ratio

Figure 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.

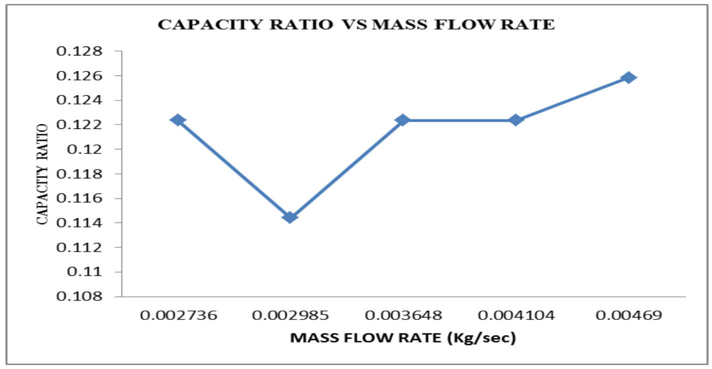

Fig 4 Capacity Ratio vs Mass Flow Rate

From figure 4 we can write that with increasing mass flow rate there is increase in capacity ratio by 10%. So maintain high value of capacity ratio mass flow rate must be high.

3.3 Effect of Mass Flow Rate on Overall Heat Transfer Coefficient

For mass flow rate 0.1616Kg/sec the overall heat transfer coefficient is 51.1405w/m2k and with increasing mass flow rate it also increases. When mass flow rate is 0.2693Kg/secthen overall heat transfer coefficient is 85.2341w/m^{2}k. So we can write that overall heat transfer coefficient increase by 40% and therefore it is better to have more mass flow rate to obtain the higher overall heat transfer coefficient.

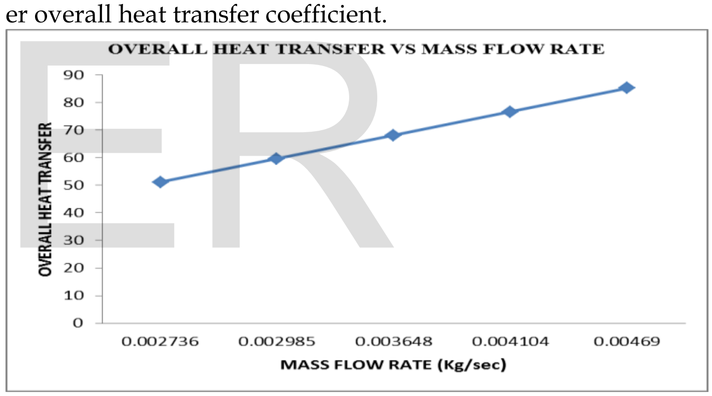

Fig 5 Overall heat transfervs mass flow rate

3.4 Effect of Mass Flow Rate on Effectiveness

In figure 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 times than the first reading.

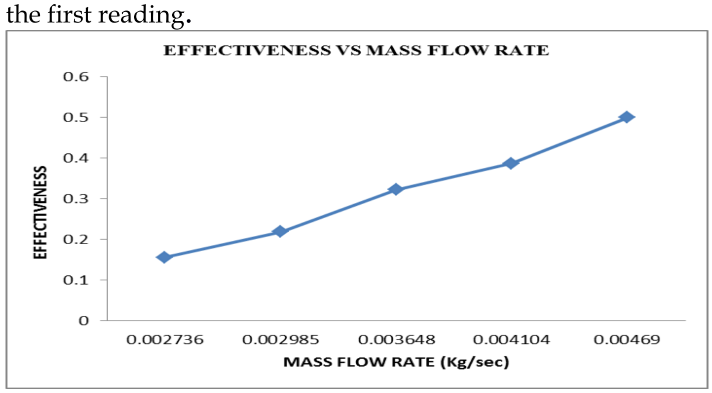

Fig 6 Effectiveness vs Mass Flow Rate

3.5 Comparison of Experimental and ANSYS Result

The comparison in between experimental value and ANSYS value. These values differ by some amount because experimental value obtains with all condition which practically effects on the system but analytical model consider only the boundary conditions. Therefore analytical value observed to be higher than the experimental value.

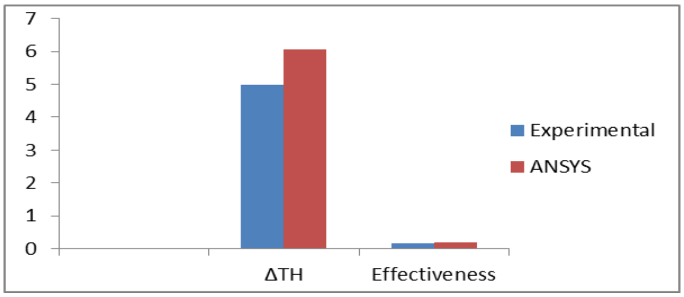

Fig 7 Comparison of Experimental Ansys

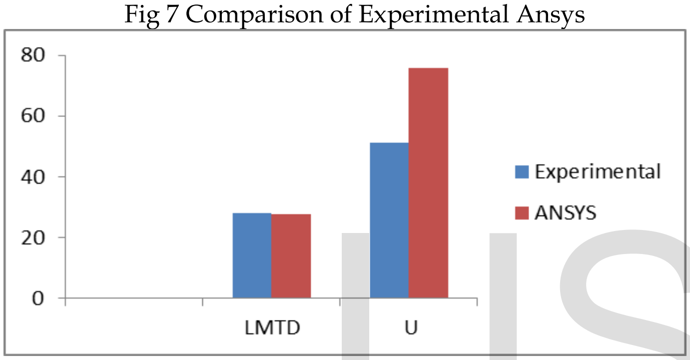

Fig 8 Comparison of Experimental Ansys

4 CONCLUSION

Design and fabrication of heat pipe cooler is tested experimentally and analytically using computer software and conclusion are made as mentioned below:

1. It is observed that with changing mass flow the LMTD value goes on changing inversely and decrement observed up to 34%.
2. In this system capacity ratio and effectiveness is increased with increasing the mass flow rates. This indicates that the hydraulic cooler is more efficient at higher mass flow rates. Maximum effectiveness observed in this system is 0.5.
3. The Overall heat transfer coefficient isalso increases by 40% with increase in mass flow rate it means heat transfer capability increases with in mass flow rate.
4. From the simulation of system it is observed that stress produced in system 1.23N/mm2 is too below the allowable stress 130N/mm2value which ensures safe design if the system.
5. The results obtained from experimental set up and analytical software is close to each other.
6. It is also observed that the heat dissipated from system is more than the heat generated in system. It concludes that cooler does not come into situation of overheating.

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