Heat Pipe Cooling System for Hydraulic Power Pack Tanks

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Abstract- *Hydraulic power packs are most commonly used power sources in industry. The progress in recent years has offered high efficiency and reliable hydraulic components, yet hydraulic tank design is often neglected part of the development. Hydraulic power units are types of equipment, from which the user expects an energy saving and reliable operation with minimum maintenance problems. One aspect of the hydraulic tank design is prevention of overheating of the hydraulic oil.. Letting oil temperature rise beyond recommended limits can reduce the life of a system due to poor lubrication, higher internal leakage, a higher risk of cavitation, and damaged components. Keeping temperatures down also helps ensure the oil and other components last longer. Excess heat can degrade hydraulic oil, form harmful varnish on component surfaces, and deteriorate rubber and elastomeric seals. Operating within recommended temperature ranges increases a hydraulic system's availability and efficiency, improving equipment productivity .Finally, with more machine uptime and fewer shutdowns, it reduces service and repair costs Considering the benefits coolers offer, it's apparent that accurately sizing them is a paramount concern for design engineers. Under sizing obviously allows higher-than-recommended oil temperatures. But over sizing hurts system efficiency as well, by reducing temperatures below the recommended range and increasing costs with a larger-than-necessary purchase. Objective of this paper is to develop an integrated cooling system in the hydraulic tank itself by use of heat pipes and innovative fin structures. The hydraulic tank is to be fitted with oil cooler modules arranged in series on the tank surface lined along the wall of the tank. The use of heat pipe will result into better overall heat transfer whereas the innovative fin structure will offer maximum surface area in minimal space. A dedicated pump system with minimal power consumption is provided with system for effective flow of oil through the oil cooler system. Here the individual modules will cooled by a dedicated fan.*

Keywords:- Fins, Heat Dissipation, Heat Pipe, Hydraulic Tank, LMTD, Overall Heat Transfer Coefficient, Effectiveness, Capacity Ratio

NOMENCLATURE

Symbol	**Description**
m	Mass flow rate in Kg/s
Cp	Specific heat in KJ/kg °K
ΔT	Temperature change in °K.
A	Surface Area of fin, m^2.
Th	Oil temperature, °C
Tc	Air temperature, °C
ΔT_{lm}	Log mean temperature difference
Q	Heat dissipation, W
U	Overall heat transfer coefficient, W/m^2k

I. INTRODUCTION

All electronic components, from microprocessors to high end power converters, generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher through put in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. The heat pipe is meeting this need and is rapidly becoming a main stream thermal management tool. Heat pipes have been commercially available since the mid 1960′s. Only in the past few years, however, has the electronics industry embraced heat pipes as reliable, cost-effective solutions for high end cooling applications. The purpose of this work is to explain basic heat pipe operation, review key heat pipe design issues, and to discuss current heat pipe electronic cooling applications.

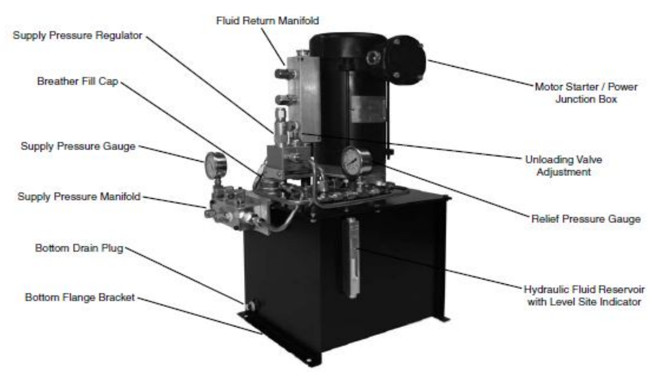

Fig.1. Hydraulic Power Pack[12]

The Hydraulic Power Pack (HPP) is stand alone unit with no assembly required other than filling the hydraulic reservoir with fluid. The unit is located as close as possible to the valve it will operate. For the protection against exposure to standing or runoff water, the unit is fixed on a flat level hard surface, such as concrete. The bottom flange bracket provide four bolt holes which should be used to fixed the unit place, minimizing vibration.[12]

Fill the reservoir to the midpoint of the hydraulic tank. Monitor the fluid level during startup of the system. Alternative hydraulic fluid can be used if they fall within the viscosity range in the operating temperature range of the system.[12]

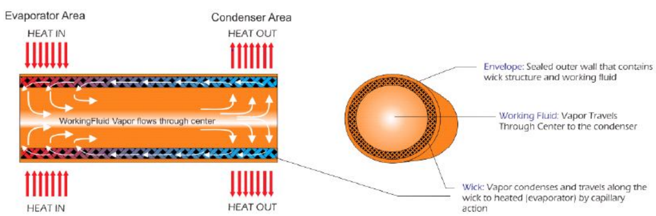

Fig.2. Heat Pipe Operation [1]

Heat pipes are passive two-phase heat transfer devices that attain low thermal resistance by exploiting the thermophysical properties of a working fluid. The working fluid operates inside a sealed envelope, typically copper for electronics cooling applications. A wick structure lines the interior wall to pump the liquid along the length of the pipe via capillary force. The copper tube is drawn under a vacuum, thus the fluid inside the pipe exists at the boundary between its liquid and vapor state,known as the saturation curve. Any amount of heat input through the copper wall vaporizes the liquid that is contained in the wick structure in the region known as the evaporator. The higher local pressure of this region drives the vapor and its sequestered heat to the colder, lower pressure region of the pipe known as the condenser. Here, the vapor condenses into liquid on the copper wall, passing off its latent heat of vaporization in the process. The wick structure then pumps the liquid back to the evaporator to absorb more heat. This process loops continuously as long as a temperature gradient exists between two points along the length of the heat pipe.[1]

II. LITERATURE SURVEY

In view of proposed paper work concerned, following few are the researchers have done their experimental study and investigated results which have been review as follows:
Darren Campo et al [1] studied, the enhancing thermal performance in embedded computing for ruggedized military and avionics applications. This experiment concluded that, the direct heat pipe integration or heat pipe bolt-on solutions give suppliers great flexibility to meet thermal requirements without compromising other design goals like size, weight, or device capabilities.

Dan Pounds et al [2] studied experimentally, the high heat flux heat pipes embedded in metal core printed circuit boards for LED thermal management. This experiment can be concluded that these novel low evaporative resistance wick structures will enable high heat flux dissipation at the circuit board level with the use of embedded heat pipes. These advanced heat spreaders will provide means of PCB level thermal management for next generation of high brightness LEDs.

G. Canti et al [3] studied, the transient behaviour of a heat pipe with extracapillary circulation. The result of study shows that the system can approach steady state condition, at a pressure of 4 bar and with a heat flux transferred of about 150 W/sq.cm, supporting an electic power step of about 1.8 kW. R K Sarangi et al [4] studied, the experimental investigations for start up and maximum heat load of closed loop pulsating heat pipe. It was observed that start up heat load does not vary with fill ratio. The optimum fill ratio depends on thermo physical properties of working fluid, operating temperatures and PHP parameters.

S.M. Peyghambarzadeh et al [5] evaluated, the thermal performance of different working fluids in a dual diameter circular heat pipe. In this study, the heat transfer performance of a 40 cm-length circular heat pipe with screen mesh wick is experimentally investigated. Results demonstrate that higher heat transfer coefficients are obtained for water and ethanol in comparison with methanol.

R. Yogev et al [6] evaluated, the PCM storage system with integrated active heat pipe. Experimental results indicate that, the active heat pipe configuration of PCM thermal storage has a potential to mitigate the effect of low thermal conductivity of the PCM.

William G. Anderson et al [7] studied, the intermediate temperature heat pipe life tests and analyses. The results indicate that the tested envelope materials and working fluids can form viable material/working fluid combinations.
CalinTarau et al [8] investigated, the variable conductance heat pipe operated with a stirling convertor. This investigation concluded that the VCHP was successfully tested with a high temperature Stirling convertor, all test objectives were achieved demonstrating proof-of-concept of ACT’s heat pipe.

Katharina Morawietz et al [9] studied, the integrated development and modeling of heat pipe solar collectors. This study concluded that the integrated development approach proposed represents a promising method to overcome current drawbacks of heat pipe solar collectors sustainably and thus exploit their potential successfully.

Steffen Jack et al [10] evaluated, the flat plate aluminum heat pipe collector with inherently limited stagnation temperature. . The study concluded that, this kind of collector a simpler hydraulic interconnection of the collector array without problems of nonuniform flow, a longer lifetime of the solar fluid, a smaller expansion vessel and overall less expensive components inside the solar loop due to lower stagnation temperatures can be achieved.

Senthilkumar R et al [11] studied, the effect of inclination angle in heat pipe performance using copper nanofluid. The obtained experimental results depict that the nanofluids have a great potential for heat transfer which makes them suitable for use in many applications than the conventional cooling mediums.

III. EXPERIMENTAL SETUP

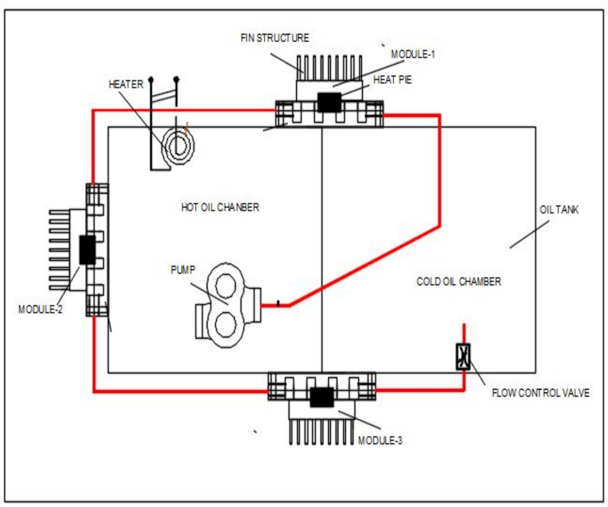

Fig.3. Layout of hydraulic oil cooler with heat pipe and fin modules

The testing setup is shown in fig. 4 with the innovative fin structure and heat pipe modules. Three numbers of module are mounted on the wall of the hydraulic tank in series. Here the individual module are cooled by the dedicated fan. A dedicated pump system with minimum power consumption is provided with system for effective flow of oil through the oil cooler system.

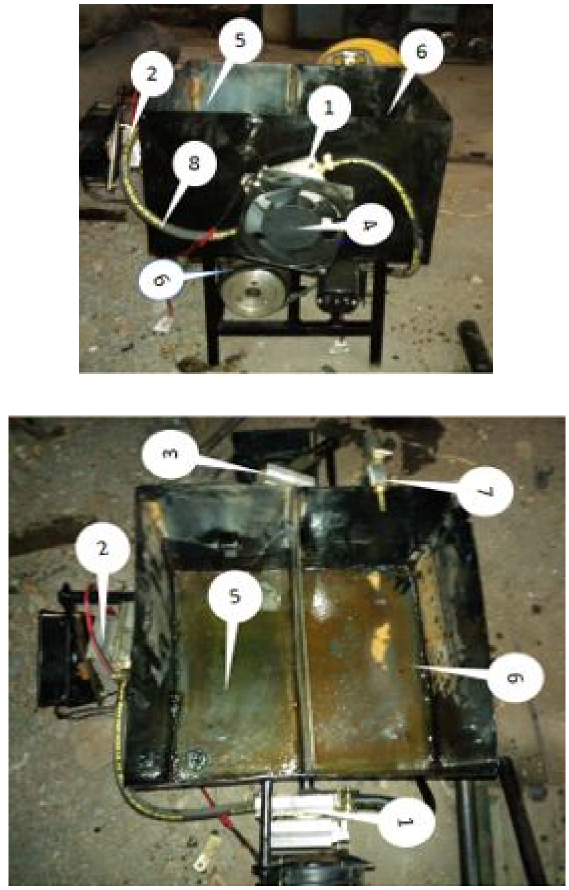

Fig. 4. Hydraulic tank with innovative fin structure and heat pipe module on the wall.

The test setup shown in fig. 4 with the innovative fin structure and heat pipe module. The 3 modules are mounted on the wall of tank in series. Here the individual module are cooled by dedicated fan. A dedicated pump system with minimum power consumption is provided with system for effective flow of oil. The hot oil from the system are collected in tank and with the help of pump the oil is supplied towards the heat pipe module. After flowing through the three module the cold oil is stored in another part of tank and then supplied towards the system.

The test setup shown in fig. 4 contain fin and heat pipe module (1,2,3), fan(4), hot oil chamber(5), cold oil chamber(6), flow control valve(7), oil flow channel(8) and pump(9).

The study is embodied as,

$$q = mc_p\Delta T = UA\Delta T_{lm} \qquad (1)$$

Where,
q is heat transfer rate
m is mass flow rate

c_p is specific heat of fluid
ΔT is temperature difference
U is overall heat transfer coefficient
A is area

$$LMTD = \frac{\Delta T_I - \Delta T_{II}}{\ln(\Delta T_I / \Delta T_{II})} \quad (2)$$

Where,

$$\Delta T_I = T_{hi} - T_{co} \quad (3)$$

$$\Delta T_{II} = T_{ho} - T_{ci} \quad (4)$$

T_{hi} is hot oil inlet temperature
T_{ho} is hot oil outlet temperature
T_{ci} is cold oil inlet temperature
T_{co} is cold oil outlet temperature

$$C = \frac{(mc_p)min}{(mc_p)max} \quad (5)$$

Where,
C is capacity ratio

$$\varepsilon = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}} \quad (6)$$

Where,
ε is effectiveness

Procedure:

1. Heat oil in the top tank upto desired temperature.
2. Start flow of oil in downward direction for counter flow configuration.
3. Start to send air bottom to top for counter flow.
4. Take mass flow readings for hot oil and also note temperature gradient of oil and air.

Table I: Observation Mode I

Sr. No.	Volume In Beaker	Time (Sec)	Mass Flow of Oil(Kg/Sec)	Air Inlet Temp. (Tci)	Air Oultlet Temp (Tco)	Oil Inlet Temp. (Thi)	Oil Oultlet Temp. (Tho)	ΔT air	ΔT oil	mCp□T (oil) $\times 10^3$ watt	mCp□T (air) $\times 10^3$ watt	LMTD	Capacity Ratio	Effectiveness	U W/ m²k
1.	200	35	0.0052	28	36	90	66	8	24	0.2121	0.52059	45.97738	0.118865	0.3870967	42.24904
2.	200	30	0.00584	28	38	89	63	10	26	0.2581	0.59496	43.37936	0.133495	0.4262295	51.17641
3.	200	25	0.007	28	35	90	60	7	30	0.357	0.7437	41.19398	0.160011	0.4838709	67.36421
4.	200	20	0.0087	28	38	88	56	10	32	0.4732	0.96681	36.68357	0.198871	0.5333333	98.34104
5.	200	15	0.0116	28	39	91	51	11	40	0.7888	1.18992	33.58271	0.265161	0.6349206	132.2109

Table II: Observation Mode II

Sr. No.	Volume In Beaker	Time (Sec)	Mass Flow of Oil(Kg/Sec)	Air Inlet Temp. (Tci)	Air Oultlet Temp (Tco)	Oil Inlet Temp. (Thi)	Oil Oultlet Temp. (Tho)	ΔT air	ΔT oil	mCp□T (oil) $\times 10^3$ watt	mCp□T (air) $\times 10^3$ watt	LMTD	Capacity Ratio	Effectiveness	U W/ m²k
1.	200	35	0.0052	28	34	85	60	6	25	0.221	0.44622	40.76468	0.118865	0.438596491	40.84418
2.	200	30	0.00584	28	35	86	54	7	32	0.31766	0.52059	37.1069	0.133495	0.551724138	52.34875
3.	200	25	0.007	28	37	85	51	9	34	0.4046	0.66933	33.98093	0.160011	0.596491228	73.49711
4.	200	20	0.0087	28	40	85	49	12	36	0.53244	0.89244	31.49028	0.198871	0.631578947	105.7469
5.	200	15	0.0116	28	42	86	46	14	40	0.7888	1.04118	29.0887	0.265161	0.689655172	133.557

Table III: Observation Mode III

Sr. No.	Volume In Beaker	Time (Sec)	Mass Flow of Oil(Kg/Sec)	Air Inlet Temp. (Tci)	Air Oultlet Temp (Tco)	Oil Inlet Temp. (Thi)	Oil Oultlet Temp. (Tho)	ΔT air	ΔT oil	mCp□T (oil) $\times 10^3$ watt	mCp□T (air) $\times 10^3$ watt	LMTD	Capacity Ratio	Effectiveness	U W/m^2k
1.	200	35	0.0052	28	34	80	55	6	25	0.221	0.44622	35.66036	0.118865	0.480769231	46.6905
2.	200	30	0.00584	28	35	81	51	7	30	0.29784	0.52059	33.18199	0.133495	0.566037736	58.5408
3.	200	25	0.007	28	37	80	48	9	32	0.3808	0.66933	30.04698	0.160011	0.615384615	83.11982
4.	200	20	0.0087	28	40	80	46	12	34	0.50286	0.89244	27.55139	0.198871	0.653846154	120.865
5.	200	15	0.0116	28	42	81	45	14	36	0.70992	1.04118	26.49491	0.265161	0.679245283	146.632

Table IV: Observation Mode IV

Sr. No.	Volume In Beaker	Time (Sec)	Mass Flow of Oil(Kg/Sec)	Air Inlet Temp. (Tci)	Air Oultlet Temp (Tco)	Oil Inlet Temp. (Thi)	Oil Oultlet Temp. (Tho)	ΔT air	ΔT oil	mCp□T (oil) $\times 10^3$ watt	mCp□T (air) $\times 10^3$ watt	LMTD	Capacity Ratio	Effectiveness	U W/m^2k
1.	200	35	0.0052	28	34	75	53	6	22	0.19448	0.44622	32.34308	0.118865	0.468085106	51.47933
2.	200	30	0.00584	28	36	75	51	8	24	0.23827	0.59496	30.29916	0.133495	0.510638298	73.26936
3.	200	25	0.007	28	37	76	49	9	27	0.3213	0.66933	29.07732	0.160011	0.5625	85.89169
4.	200	20	0.0087	28	38	75	45	10	30	0.4437	0.7437	25.71671	0.198871	0.638297872	107.9065
5.	200	15	0.0116	28	39	75	43	11	32	0.63104	0.81807	23.98715	0.265161	0.680851064	127.2556

Table V: Observation Mode V

Sr. No.	Volume In Beaker	Time (Sec)	Mass Flow of Oil(Kg/Sec)	Air Inlet Temp. (Tci)	Air Oultlet Temp (Tco)	Oil Inlet Temp. (Thi)	Oil Oultlet Temp. (Tho)	ΔT air	ΔT oil	mCp□T (oil) $\times 10^3$ watt	mCp□T (air) $\times 10^3$ watt	LMTD	Capacity Ratio	Effectiveness	U W/m^2k
1.	200	35	0.0052	28	33	70	48	5	22	0.19448	0.37185	27.63394	0.118865	0.523809524	50.21
2.	200	30	0.00584	28	34	70	46	6	24	0.23827	0.44622	25.96851	0.133495	0.571428571	64.11611
3.	200	25	0.007	28	36	71	44	8	27	0.3213	0.59496	24.27311	0.160011	0.627906977	91.45925
4.	200	20	0.0087	28	37	70	42	9	28	0.41412	0.66933	22.15872	0.198871	0.666666667	112.7096
5.	200	15	0.0116	28	38	70	40	10	30	0.5916	0.7437	20.39091	0.265161	0.714285714	136.0901

IV. RESULT AND DISCUSSION

The results obtained from the study are given below,

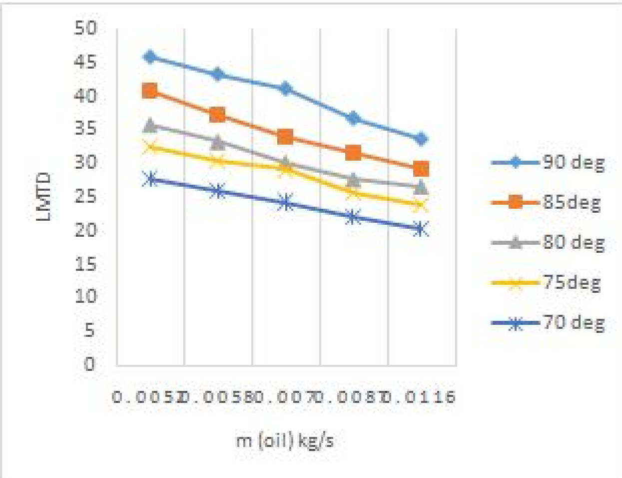

Fig. 5. LMTD Vs Mass Flow Rate of Oil

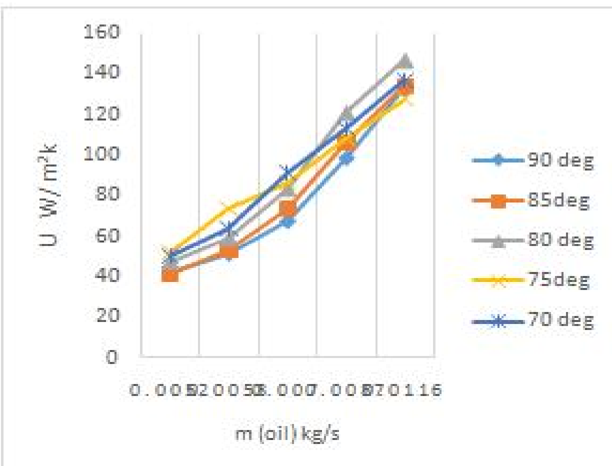

Fig. 6. Overall H.T. Coeff. Vs Mass Flow Rate of Oil

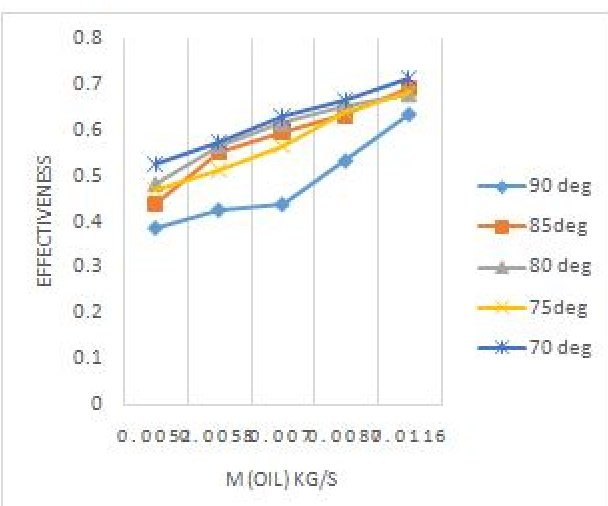

Fig. 7. Effectiveness Vs Mass Flow Rate of Oil

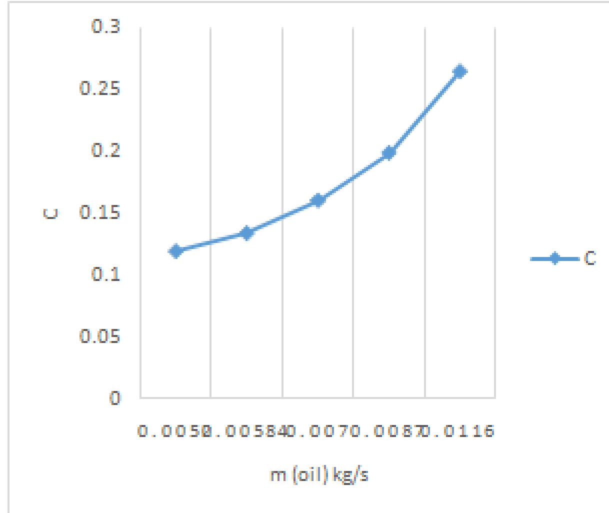

Fig. 8. Capacity Ratio Vs Mass Flow Rate of Oil

1. The temperature readings set for the experiment is 90°C, 85°C, 80°C, 75°C, and 70°C as initial temperature for oil.

2. As the log mean temperature difference is decreases, the heat dissipation from the system increases which increases the effectiveness of the rig.

3. Fig. 5 shows that with the help of heat pipe and innovative fin structure the log mean temperature difference is decreases step by step for all the temperature readings at different mass flow rate.

4. Fig. 6 show that, as the log mean temperature difference is decreases, the overall heat transfer coefficient is increases. The maximum value for overall heat transfer coefficient obtained are 136.090 W/m^2k, 127.155 W/m^2k, 146.632 W/m^2k, 133.557 W/m^2k and 132.210 W/m^2k at temperature 70°C, 75°C, 80°C, 85 °C, and 90°C at flow rate of oil 0.0116 Kg/s.

5. Fig. 7 shows that, at five different mass flow rate of oil, the maximum effectiveness calculated as 0.7142, 0.6808, 0.6792, 0.6896 and 0.6349 at temperature 70°C, 75°C, 80 °C, 85°C, and 90°C at flow rate 0.0116 Kg/s of oil and overall heat transfer coefficient 136.090 W/m^2k, 127.155 W/m^2k, 146.632 W/m^2k, 133.557 W/m^2k and 132.210 W/m^2k.

6. Fig. 8 shows the capacity ratio, which found as 0.2651.

V. CONCLUSIONS

1. The heat pipe enhanced oil cooler module demonstrated through the experimentation. The three module is fitted on the wall of hydraulic tank is made up of copper heat pipe with water as working fluid and aluminum plate heat sink, the individual fan is provided on each module for cooling. These whole system work as oil to air heat exchanger.

2. 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. Dissipating maximum heat cools oil which improves its viscosity.

3. As the viscosity is more the pumping power require for oil will also be less this is an advantage of efficient oil cooler.

4. Throughout all the experimentation procedure the maximum effectiveness is found out as 0.7142 at 0.0116 Kg/s flow rate of oil.

5. The overall heat transfer coefficient found are 136.090 W/m^2 k, 127.155 W/m^2 k, 146.632 W/m^2 k, 133.557 W/m^2 k and 132.210 W/m^2 k at all temperature readings.

6. The maximum capacity ratio is found out for rig is 0.2651.
   Following are the future scope of this experimental study,
    1. Power packs for Press machines
    2. Power packs for earth moving equipment
    3. Control panel cooling
    4. CNC machine controller cooling.

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