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Design and Comparative Analysis of Straight Fin and 8-Channel Staggered Profile Vertical Tower Cooler in Hydraulic Oil Cooler Applications.

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ABSTRACT

Hydraulic circuits are most commonly used power sources in industry. The progress in recent years has offered high efficiency and reliable hydraulic component, yet hydraulic cooling circuit design is often neglected part of the development. One aspect of the hydraulic circuit design is prevention of overheating of hydraulic oil. Letting oil temperature rise beyond particular limit can increase the power consumption reduce the life of a system due to poor lubrication, higher internal leakage, higher risk of cavitation and damage component. Keeping temperature down also help ensure the oil and other components last longer. Excess heat can degrade hydraulic oil, form harmful varnish on component surface and deteriorate rubber and elastomeric seal. Operating within recommended temperature ranges increases a hydraulic system availability and efficiency , improving equipment productivity. Finally , with more machine uptime and fewer shutdowns, it reduces service and repair costs. Considering the benefit of cooler offer, it's apparent that accurately sizing them is paramount concern for design engineers. Presently hydraulic oil cooler used is shell and tube type oil coolers with water as the cooling medium , this is extremely bulk and running cost is high hence it is needed to be replaced by another system that will be air cooled to make provision for lower space consumption and cost reduction. Two designs of fins were thought of namely the straight fin system with fins project outward in eight channels and the other design being anstraight fin system with fins project outward in eight channels the equipment to be developed will be first modeled using Unigrafix Nx-8 and steady state thermal analysis will be done using Ansys workbench 16.0. The paper will also discuss the performance evaluation of the straight fin setup.

Keywords: hydraulic oil cooler, straight fin system with fins project outward in eight channels,8-channel staggered profile vertical tower cooler.

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I. INTRODUCTION

Two types of heat exchanger are used to cool hydraulic oil:

1) Shell-and-tube.
2) Finned tube.

The shell-and-tube has a series of tubes inside a closed cylinder. The oil flows through the small tubes, and the fluid receiving the heat (typically water) flows around the small tubes. Routing of the oil can be done to produce a single pass (oil enters one end and exits the other end) or a double pass (oil enters one end, makes a U-turn at the other end, and travels back to exit at the same end it entered).

A shell and tube heat exchanger is a class of heat exchanger designs.] It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

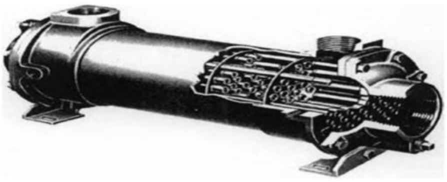


Fig. 1 Shell and Tube type heat exchanger

The finned tube exchanger is used for oil-to-air exchange. The air may be forced through the exchanger with a fan or may flow naturally. If an oil cooler is used on a mobile machine, it is the finned tube type.

1.1 Types of Finned Tubes

a. Longitudinal Fins

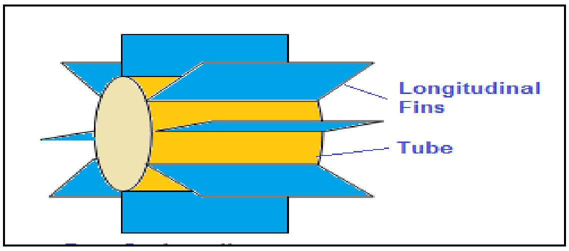


Fig. 2 - Longitudinally finned tube in heat exchanger

Longitudinal fins on a tube are best suited for applications where the flow outside the tubes is expected to be streamlined along the tube length, for example double pipe heat exchangers with highly viscous fluid outside the finned tube.

Longitudinal fins on a tube run along the length of the tubes. The cross sectional shapes of longitudinal fins can be either flat or tapered. For different cross sectional geometries, various correlations are available in the literature to evaluate the heat transfer coefficients on outer side of the tubes.

b. Transverse Fins

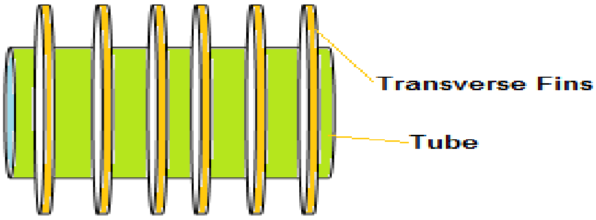


Fig. 3 - Transversely finned heat exchanger tube

Transverse fins are normally used for gas flows or turbulent flows and for cross flow type exchangers or shell and tube heat exchangers. For air coolers, tubes with transverse fins are best suited.

II. LITERATURE REVIEW

[1]Mark E. Steinke and Satish G. Kandlikar are performed the experimental work in Single Phase Liquid Heat Transfer in Plain and Enhanced Microchanels.

The development of advanced micro channel heat exchangers and microfluidic devices is dependent upon the understanding of the fundamental heat transfer processes that occur in these systems. There have been great advancements in our understanding of the heat transfer and fluid flow mechanisms that occur in micro channels. There is several research areas in micro channel heat transfer that so promise for such applications as microprocessor cooling.

[2]Satish G. Kandlikar and William J. Grande are performed the experimental work in Evolution of Micro channel Flow Passages – Thermo hydraulic Performance and Fabrication Technology.

This paper provides a roadmap of development in the thermal and fabrication aspects of micro channels as applied in the microelectronics and other high heat-flux cooling applications. Micro channels are defined as flow passages that have hydraulic diameters in the range of 10 to 200 micrometers. The impetus for micro channel research was provided by the pioneering work of Tuckerman and Pease at Stanford University in the early eighties. Since that time, this technology has received considerable attention in microelectronics and other major application areas, such as fuel cell systems and advanced heat sink designs.

[3]Haishan Cao, Guangwen Chen and Quan Yuan are performed the experimental work in Testing and Design of a Micro channel Heat Exchanger With Multiple Plates.

The micro heating system is one of the hard cores of a micro chemical system. In this paper, the performance of micro channel heat exchangers (MCHEs) with two plates made of stainless steel was investigated experimentally. The maximum volumetric heat transfer coefficient was up to 5.2 MW/m3 •K with a corresponding pressure drop of less than 20 kPa under a Reynolds number of around 65.

[4]Robert K. Lade Jr., Erik J. Hippchen, Luke Rodgers, Christopher W. Macosko, and Lorraine F. Francis are performed the experimental work in Capillary-Driven Flow in Open Micro channels Printed with Fused Deposition Modeling.

The fundamentals of fluid flow in 3D printed, open micro channels created using fused deposition modeling (FDM) are explored. Printed micro channels are used in microfluidic devices and have potential applications in embedding electronics in plastic substrates.

[5]Yanhui Hana, Yan Liua and Ming Liaa ,JinHuanga are performed the experimental work in A review of development of micro-channel heat exchanger applied in air-conditioning system.

Micro-channel heat exchanger(MCHX) has been increasingly applied in HVAC&R(Heating, Ventilation, and Air Conditioning & Refrigeration) field due to its higher efficiently heat transfer rate, more compact structure, lower cost.

[6]Jang-Won Seo, Yoon-Ho Kim, Dongseon Kim, Young-Don Choi and Kyu-Jung Lee are performed the experimental work in Heat Transfer and Pressure Drop Characteristics in Straight Micro channel of Printed Circuit Heat Exchangers.

Performance tests were carried out for a micro channel printed circuit heat exchanger (PCHE), which was fabricated with micro photo-etching and diffusion bonding technologies.

[7] Julian Marschewski, Raphael Brechbühler, Stefan Jung, Patrick Ruch and Bruno Michel ,DimosPoulikakos are performed the experimental work in Significant heat transfer enhancement in micro channels with herringbone-inspired microstructures.

Herringbone microstructures are a very promising class of flow promoters to passively enhance heat transfer in micro channels by efficiently triggering helicoidal fluid motion. A host of applications are envisioned to benefit from heat transfer enhancement in micro channels, including microfluidic interlayer cooling of 3D electronic chip stacks, or advanced concepts of integrated cooling and electrochemical power delivery.

[8] Ngoctan Tran, Yaw-Jen Chang, Jyh-tong Teng and Thanhtrung Dang are performed the experimental work in Numerical and Experimental Investigations on Heat Transfer of Aluminum Micro channel Heat Sinks with Different Channel Depths.

In this study, heat transfer of aluminum micro channel heat sinks (MCHs) was investigated with both numerical and experimental methods. Five MCHs, each with twelve channels, were designed with the channel width of 500 µm, channel length of 33 mm, and channel depths varying from 200 µm to 900 µm.

III. PROBLEM STATEMENT

Overheating ranks No. 2 in the list of most common problems with hydraulic equipment. Unlike leaks, which rank No. 1, the causes of overheating and its remedies are often not well understood by maintenance personnel.

Why do Hydraulic Systems Overheat?

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’s 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.

Hydraulic Fluid Temperature

How hot is too hot? Hydraulic fluid temperatures above 180°F (82°C) damage most seal compounds and accelerate degradation of the oil. While 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.

Maintaining Stable Hydraulic Fluid Temperature

To achieve stable fluid temperature, a hydraulic system’s capacity to dissipate heat must exceed its heat load. For example, a system with continuous input power of 100 kW and an efficiency of 80 percent needs to be capable of dissipating a heat load of at least 20 kW. Assuming this system has a designed cooling capacity of 25 kW, anything that increases heat load above 25 kW or reduces the cooling system’s capacity below 25 kW will cause the system to overheat.

Methods to solve overheating problems

There are two ways to solve overheating problems in hydraulic systems: decrease heat load or increase heat dissipation.

Hydraulic systems dissipate heat through the reservoir. Therefore, check the reservoir fluid level and if low, fill to the correct level. Check that there are no obstructions to airflow around the reservoir, such as a buildup of dirt or debris.

Inspect the heat exchanger and ensure that the core is not blocked. 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. Check the performance of all cooling circuit components and replace as necessary.

An infrared thermometer can be used to check the performance of a heat exchanger, provided the design flow-rate of hydraulic fluid through the exchanger is known. To do this, measure the temperature of the oil entering and exiting the exchanger and substitute the values in the following formula:

$$\frac{\text{kW} = \text{L/min} \times \Delta T\ ^\circ\text{C}}{34.5}$$

Where:

kW = heat dissipation of exchanger in kilowatts

L/min = oil flow through the exchanger in liters per minute

ΔT ºC = inlet oil temperature minus outlet oil temperature in Celsius.

IV. MOTIVATION

Previously Used System:

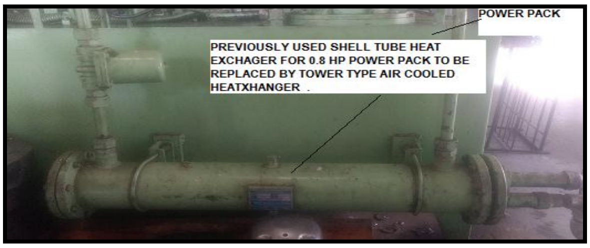


Fig 4 photo of Previously Used System

The above system is to be replaced by another compact system that will be air cooled using fan and the design will be of tower cooler type where we will be developing a single unit prototype with two profile designs for comparison purpose. The design under consideration is described below.

1. **Objective :**

a. Design and development of straight fin type profile vertical tower cooler in hydraulic oil cooler.
b. Design and development of 8-channel staggered profile vertical tower cooler in hydraulic oil cooler.
c. Thermal analysis of straight fin and 8-channel staggered profile vertical tower cooler in hydraulic oil cooler using ANSYS
d. Comparative experimental study and validation of straight fin and 8-channel staggered profile vertical tower cooler in hydraulic oil cooler as to the following parameters :
   a) Overall Heat transfer coefficient.
   b) Heat extraction ability (watt/min)
   c)Obstruction to air channel flow (mm of water column)

2. Plot comparative graphs of above parameters under various conditions

Design Methodology :

1. Design of straight fin and 8-channel staggered profile vertical tower cooler in hydraulic oil cooler system to remove the desired heat load.2-d drawing preparation of linkage mechanism by ‘ kinematic overlay method ‘ using Auto-Cad .
2. Development of 3-D model of system of oblique -staggered FDM fin holder using Unigraphix NX-8 , Preparation of STL file for model 3-D printing
3. Mechanical design of above components using theoretical theories of failure after selection of appropriate materials
4. 3-D modeling of set-up using Unigraphix Nx-8.0
5. CAE of critical component and meshing using Ansys i.e. the preprocessing part.
6. Thermal design validation using ANSYS …critical components of the system will be designed and validated.

V. EXPERIMENTAL SETUP

Fig 5 Photographic Image of Experimental Setup

Procedure of trial:

1. Heat oil in the top tank up to desired temperature.
2. Heat oil up to given temperature range.
3. Start oil flow from system at a specific flow rate by adjusting electronic speed regulator.
4. Start blower fans.
5. Take mass flow readings for hot oil and also not temperature gradient.
6. Take temperature reading of air.

VI. DESIGN AND ANALYSIS

A. Plain straight geometry tower fin cooler:

Fig 6 Photographic Image Plain Straight Geometry Tower Fin Cooler

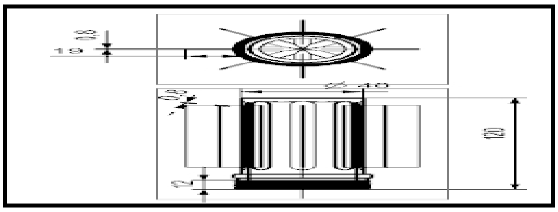


Fig 9 2DModel of Plain Straight Geometry Tower Fin Cooler

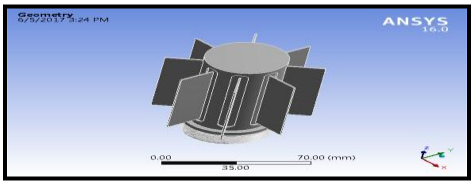


Fig 10 3D geometry of Plain Straight Tower Fin Cooler in ANSYS

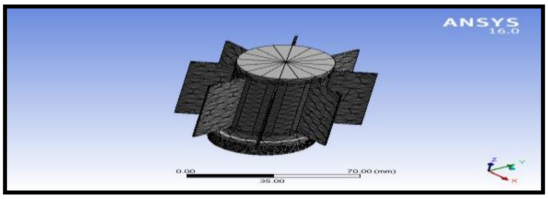


Fig 11 Nodes & elements of Plain Straight Tower Fin Cooler in ANSYS

Statistics	
Nodes	41034
Elements	22403
Mesh Metric	none

Table No.1 Nodes & elements of Plain Straight Tower Fin Cooler in ANSYS

B. 8-channel staggered profile vertical tower cooler:

Fig 12 Photographic Image of 8-channel staggered profile vertical tower cooler

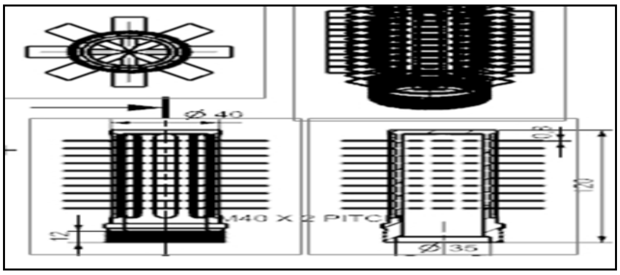


Fig.14 2-D Model of 8-channel staggered profile vertical tower cooler

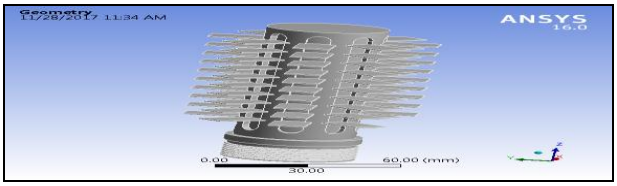


Fig. 15 3D geometry of 8-channel staggered profile vertical Tower Cooler in ANSYS

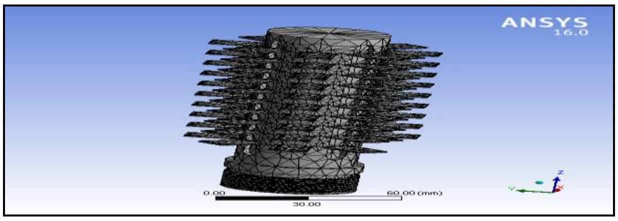


Fig. 16 Nodes & elements of 8-channel staggered profile vertical Tower Cooler in ANSYS

Statistics	
Nodes	93012
Elements	50144
Mesh Metric	none

Table No. 2 Nodes& elements of8-channel staggered profile vertical Tower Cooler in ANSYS

Test and trial on plain straight tower cooler:

Input data
Oil (hot fluid) data
SAE 20 W 40
Specific gravity = 0.913
Specific heat = 0.406 Btu/lb-f =1.7KJ/KgK
Note:1 KJ/KgK = 0.2389 Kcal/Kg oC =0.2389 Btu/ lbmoF
Hence Specific heat of SAE20W40 = 0.406*1/0.2389 = 1.6999 = 1.7 KJ/KgK
Specific heatof air at (25 to 30 oC) = 1.005 KJ/Kg-K.
Area of individual fins = 89656.000mm^2
Total effective area = individual area * 3 = 0.268 m^2

VII. OBSERVATION TABLE

[1] Straight Fin Vertical Tower Cooler

Table No. 3 Mass flow hot oil

Sr. No.	Volume in beaker	Time (sec)	Mass flow (Kg/sec)
1.	200	35	0.0052
2.	200	30	0.00584
3.	200	25	0.007
4.	200	20	0.0087
5.	200	15	0.0116

A) Mass flow rate of air :
Specification soffan : 108 cfm
Now, 1 kg /hr = 0.408cfm thus , 1 cfm =2.45 kg/hr
Thus mass flow rate of air = 108 x 2.45 =264.6 kg/hr =0.074 kg/sec
B) Temperature readings

Table No.4For Cold Air

Sr.No.	Cold air inlet temp. (Tci)	Cold air outlet temp.(Tco)	ΔT air
1.	28	7	8
2.	28	8	10
3.	28	10	7
4.	28	13	10
5.	28	16	11

Table No. 5 For Hot Air

Sr.No.	Hot oil inlet temp. (Thi)	Hot oil outlet temp. (The)	ΔT oil
1.	90	66	24
2.	89	63	26
3.	90	60	30
4.	88	56	32
5.	91	51	40

B. 8 channel staggered profile vertical tower cooler

Table No. 6Mass flow of hot oil:

Sr. No.	Volume in beaker	Time (sec)	Mass flow (Kg/sec)
1	200	35	0.005628571
2	200	30	0.006566667
3	200	25	0.00788
4	200	20	0.00985
5	200	15	0.013133333

Mass flow rate of air

Specifications of fan: 108 cfm
Now, 1 kg /hr = 0.408cfm thus, 1 cfm =2.45 kg/hr

Thus mass flow rate of air = 108 x 2.45 =264.6 kg/hr =0.074 kg/s

Table No. 7 Inlet& outlet temperature reading for cold air:

Sr. No.	Cold air inlet temp. (Tci)	Cold air outlet temp. (Tco)	ΔT air
1	28.3	33.3	5
2	28.4	35.3	6.9
3	28.6	37.3	8.7
4	29.3	39.8	10.5
5	28.5	41.5	13

Table No. 8 Inlet& outlet temperature reading for hot air:

Sr. No.	Hot oil inlet temp.(Thi)	Hot oil outlet temp.(The)	ΔT oil
1	90	60	30
2	89	58	31
3	90	56	34
4	88	52	36
5	91	48	43

VIII. RESULT AND DISCUSSION

A. Plain Straight Geometry Tower Fin Cooler

Analysis on ANSYS of Plain Straight Geometry Tower Fin Cooler:

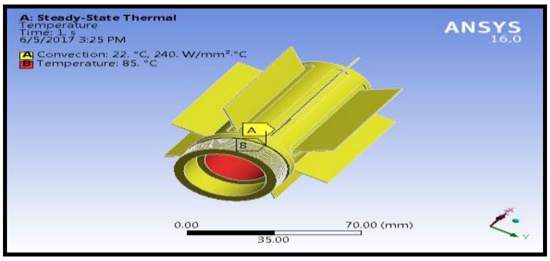


Fig 17 details of steady state thermal distribution in the Plain Straight tower cooler.

Fig 5.1 show that the outside surface of straight fin is in contact with air and thereby convective heat transfer is expected 240 W/mm2°C and the inner temperature And outer temperature is expected as taken to be 85 °C and 22 °C.

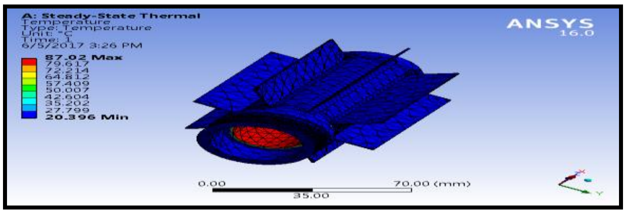


Fig 18 details of temperature distribution in the Plain Straight tower cooler.

Fig 5.2 shows that graphic above shows temperature distribution across

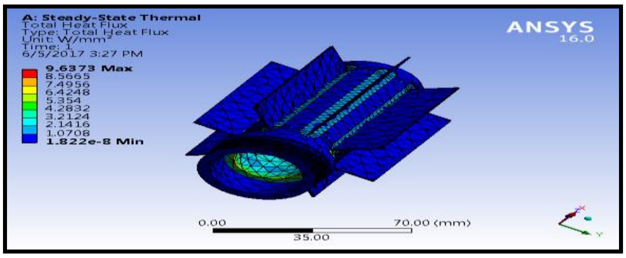


Fig 19 details of steady state heat flux distribution in the Plain Straight tower cooler.

Fig 5.3 shows that The maximum total heat flux is 9.6373 W/mm2 which is dissipated by the specimen , so we can considering this it can be valudated with the theoretical heat dissipated.

2 Result Table of Plain Straight Geometry Tower Fin Cooler:

Table No. 9 Variation in mCpΔT (oil),mCpΔT (air) and LMTD

Sr. No.	mCp∆T (oil)	mCp∆T (air)	LMTD
1	0.21216	4.61094	44.72355
2	0.258128	4.53657	41.7159
3	0.357	4.61094	38.60661
4	0.47328	4.4622	32.46064
5	0.7888	4.68531	25.4867

Table No. 10 Variation in Capacity Ratio, Effectiveness and Overall heat transfer coefficient

Sr. No.	Capacity Ratio	Effectiveness	U W/ m^2k
1	0.046012	0.387096774	307.2321
2	0.056899	0.426229508	264.4922
3	0.077425	0.483870968	215.0625
4	0.106064	0.533333333	160.0962
5	0.168356	0.634920635	136.582

B. 8-Channel staggered profile vertical tower cooler:

Table No. 11 Variation in mCp∆T (oil), mCp∆T (air) and LMTD

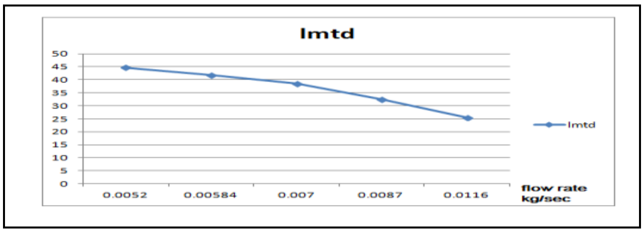
Sr. No.	mCp∆T (oil)	mCp∆T (air)	LMTD
1	0.705485	2.812761	31.1779
2	0.850502	2.841849	27.0401
3	1.11937	3.041507	24.0456
4	1.481519	3.068018	21.5133
5	2.359456	3.23626	19.3311

Table No. 12 Variation in Capacity Ratio, Effectiveness and Overall heat transfer coefficient

Sr. No.	Capacity Ratio	Effectiveness	U W/ m^2k
1	0.071662	0.277778	200.4811
2	0.085508	0.405882	233.5502
3	0.105152	0.483333	281.087
4	0.137969	0.65625	316.9118
5	0.208305	0.684211	372.0269

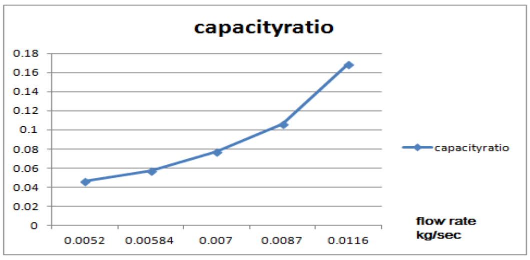
11. Plotted Graph:

A. Plain Straight Geometry Tower Fin Cooler:



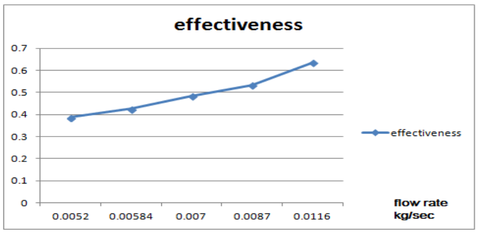
Graph 1: Variation LMTD with flow rate

Above graph 5.1 shows that logarithmic mean temperature difference Plain Straight Geometry Tower Fin Cooler decreases with increase in flow rate of oil.



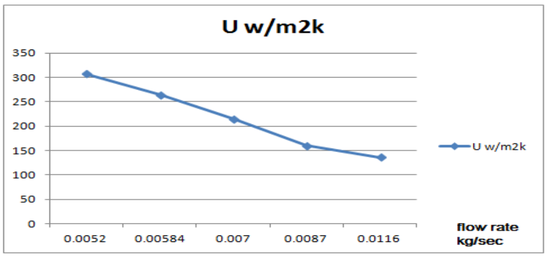
Graph2: Variation Capacity ratio with flow rate

Capacity ratio for Straight Geometry Tower Fin Cooler is increases with increase in flow rate of oil.



Graph 3: Variation Effectiveness with flow rate

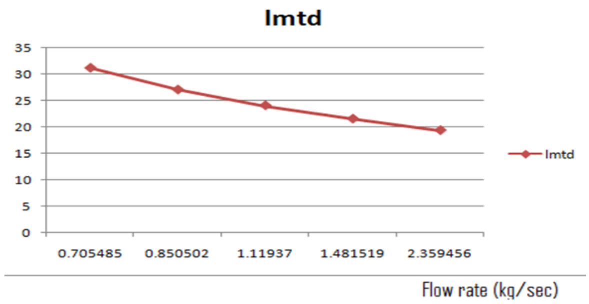
Above graph 5.shows that effectiveness of Plain Straight Geometry Tower Fin Cooler is increases with increase in flow rate of oil.



Graph 4: Variation Overall heat transfer coefficient with Flow rate

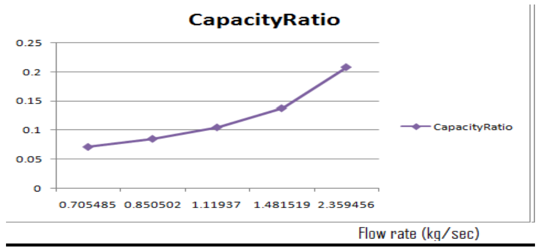
Above graph 5.4 shows that Overall heat transfer coefficient of Plain Straight Geometry Tower Fin Cooler is decreases with increase in flow rate of oil.

B. 8-channel staggered profile vertical tower cooler:



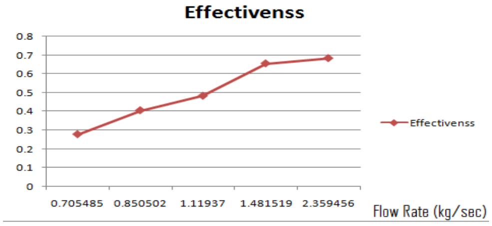
Graph 5: Variation LMTD with flow rate

Above Graph 5.5 shows that Logarithmic mean temperature difference of 8-channel staggered profile vertical tower cooler decreases with increase in flow rate of oil.



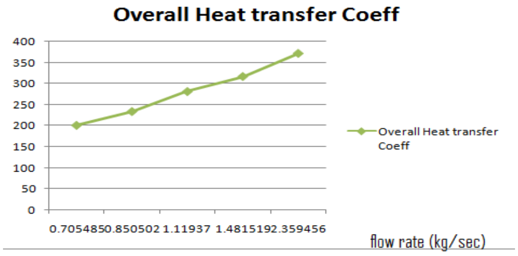
Graph 6: Variation Capacity ratio with flow rate

Above Graph 5.6 shows that Capacity ratio of 8-channel staggered profile vertical tower cooler increases with increase in flow rate of oil.



Graph 7: Variation Effectiveness with flow rate

Above Graph 5.7 shows that Effectiveness of 8-channel staggered profile vertical tower cooler improves with increase in flow rate of oil.



Graph 8: Variation Overall heat transfer coefficient with Flow rate

Above Graph 5.8 shows that Overall heat transfer coefficient of 8-channel staggered profile vertical tower cooler increases with increase in Flow rate of oil.

IX. SCOPE FOR FUTURE WORK

There can be many promising techniques and research areas for enhancing thermal performance of hydraulic oil cooler. Improvement in current technique by experimentations may also prove beneficial. Some of the possible improvements and future developments are stated below:

a. Number of fins per linear arrangement can be increased to increase heat flux.
b. 12- Channel and 16- channel staggered profile vertical tower cooler can be develop to increase performance of oil cooler.
c. Fan size can be increased to increased heat transfer rate.
d. Copper can be used for the material for channel staggered profile to increased heat transfer rate.

Temperature balance in a hydraulic system occurs when the cooler can cool down the energy input that the system does not consume – the system's lost energy (Ploss = Pcool = Pin – Pused). Temperature optimization occurs at the temperature at which the oil viscosity is maintained at recommended values.

Heat exchangers have always been at the heart of industrial heat recovery systems, but the latest advances in their design are making them even more central to manufacturing processes.

X. CONCLUSIONS

An experimental study has been carried out to design and comparative analysis of straight fin and 8-channel staggered profile vertical tower cooler in hydraulic oil cooler applications. Maximum heat flux has been varied from 9.6 watt to 11.9 watt. LMTD increases with decrease in flow rate. Overall heat transfer coefficient increases with increase in Flow rate of oil. Effectiveness improves with increase in flow rate. The correct working temperature produces a number of economic and environmental benefits:

1. The hydraulic system's useful life is extended.
2. The oil's useful life is extended.
3. The hydraulic system's availability increases – more operating time and fewer shutdowns.
4. Service and repair costs are reduced.
5. High efficiency level maintained in continuous operation – the system's efficiency falls if the temperature exceeds the ideal working temperature.

Following conclusions are made from the above mentioned experimental study and is detailed below:

1. Conclusions in Case of Straight Fin Vertical Tower Cooler:

1. Maximum heat flux is 9.6 watt.
2. LMTD decreases with decrease in flow rate as compare to Straight Fin Vertical Tower Cooler.
3. Overall heat transfer coefficient decreases with increase in Flow rate compare to Straight Fin Vertical Tower Cooler.
4. Effectiveness improves with increase in flow rate compare to Straight Fin Vertical Tower Cooler.

1. Conclusions in Case of 8-channel staggered profile vertical tower cooler:

1. Maximum heat flux is 11.9 watt.
2. LMTD increases with decrease in flow rate as compare to Straight Fin Vertical Tower Cooler.

3. Overall heat transfer coefficient increases with increase in Flow rate compare to Straight Fin Vertical Tower Cooler.
4. Effectiveness improves with increase in flow rate compare to Straight Fin Vertical Tower Cooler.

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