Heat Transfer Enhancement using Herringbone wavy & Smooth Wavy fin Heat Exchanger for Hydraulic Oil Cooling

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Abstract- Heat exchangers are employed in a wide variety of engineering applications such as air-conditioning equipment, process gas heaters, and coolers. Generally, the heat exchangers consists of a plurality of equally spaced parallel tubes through which a heat transfer medium such as water, oil, or refrigerant is forced to flow while a second heat transfer medium such as air is directed across the tubes in a block of parallel fins. The plate fin-and-tube heat exchangers are used in wide variety of industrial applications, particularly in the heating, air-conditioning and refrigeration industries. In most cases the working fluid is liquid on the tube side exchanging heat with a gas, usually air. The current study is focused on two fin configurations, first one is smooth wavy fin and second one is herringbone wavy fin. These two fin configurations are experimentally investigated for cooling of hot oil. In this work performance of two heat exchangers are analyzed, one is with smooth wavy fin and another is with herringbone wavy fin heat exchanger. The hot oil is passed through both heat exchangers at the same time and, its performance is studied, analyzed and compared. The cooling of hot oil is monitored in this study and result is presented The results of this study show that the smooth wavy fins provide efficient cooling compared to herringbone fin heat exchangers.

***Key Words**- Heat Exchanger, Herringbone wavy fin, smooth wavy fin, Heat transfer coefficient, Temperature difference, Mean mass flow rate*

I. INTRODUCTION

A heat exchanger is a device which is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. Not only are heat exchangers often used in the process, power, petroleum, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, they also serve as key components of many industrial products available in the market. The heat exchangers can be classified in several ways such as, according to the transfer process, number of fluids and heat transfer mechanism. Conventional heat exchangers are classified on the basis of construction type and flow arrangement. The other criteria used for the classification of heat exchangers are the type of process functions and fluids involved (gas-gas, gas-liquid, liquid-liquid, two phase gas etc.). The classification according to the surface compactness deals with one of the important class of heat exchanger named as compact heat exchangers. The process industries call for more and more compact designs of heat exchangers. Flow interruption created in flow at periodic intervals is a popular means for heat transfer enhancement in compact heat exchangers. Flow interruption causes enhanced heat transfer through convection and it is most preferred type of active heat transfer technique. Flow interruption can be created by pulsation, tabulators etc.The different type of enhanced surfaces or fins which are used in compact heat exchangers according to a designer's requirement. Operating temperature, cost, bonding of fins to plates, choice of materials is the important factors to selecting fins for the heat exchangers. Wavy fins are particularly demandable for their simplicity to manufacture. Their performance is also competitive with that of most efficient offset strip fins. A wavy fin specimen is manufactured by placing a number of fins (same length and height) side by side and bonding with each other to a number of equal spacing wavy fin channels. There are two basic types of wavy fin geometries. These are herringbone and smooth wavy fins. A lot of work has been done on the wavy fins but only a few works have examined smooth wavy fins and herringbone fins. Though wavy fins are not currently widely used but in recent future wavy fins can be used for many applications. Use of wavy fins will provide great option for heat transfer enhancement in passive methods, wavy fins are simple to construct hence it can be also economically beneficial for process industries.

II. CLASSIFICATION OF HEAT EXCHANGER

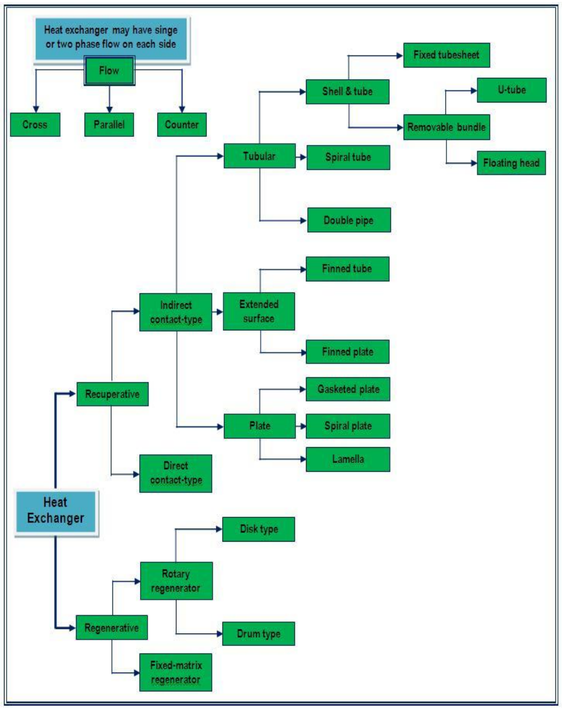


Figure 1. Classification Of Heat Exchanger

II. LITRATURE REVIEW

Lin [1] also performed an experimental study to obtain the airside performance of the herringbone geometry in wet conditions. Two different angles, 15 degree and 25 degree and spacing, 5=2.60101 and 8.40101 were considered. Flow visualization showed that a locally dry spot occurred in the wavy channel for the corrugation angle 15 degree and a fin spacing of 8.4. This phenomenon was related to the recirculation of the airflow across the apex. On the other hand that phenomenon was not clearly visible for fin spacing of 2.6. Based on their results, they reported that higher heat transfer coefficients and larger pressure drops were obtained for larger corrugation angle and smaller fin spacing

investigation of thermal-hydraulic performance for single phase laminar flows in a novel corrugated wall compact heat exchanger core. They considered the corrugation aspect ratio *(y= 2Al).)* of 0.15, and duct aspect ratio *(a = SUI)* of 0.4533 for their test geometry and obtained their experimental result for laminar flows (70 s; Re S 830), using water as a working fluids. A CFD model was also developed for their numerical study using control volume based on commercial code FLUENT to determine fully developed laminar flows. They found a good agreement (± 10%) between the numerical prediction and experimental data.

Vyas [3] performed a visualization experiment and computational simulation to study the swirl flow and enhanced heat transfer in a 2-D (plate separation to width = 0.067) sinusoidal channel having corrugation aspect ratio, *r* = 0.25 and spacing ratio, £ = 1. They carried out the computational work using finite-volume techniques for a non orthogonal non-staggered grid which agreed very well with experimentally visualized flow fields. They observed that the flow was essentially streamline and contoured to the wall waviness at low *Re* < 200 but lateral recirculation was produced in through regions of the wavy channel due to wall curvature with increasing Re > 200. Finally they reported that the swirl strength and spatial flow coverage increased with *Re* to produce temperature field which had sharper gradients at the wall with considerable thinning of the boundary layer and enhanced heat transfer.

Wang [4] has studied the airside performance of the wavy fin-and-tube heat exchangers having a larger diameter tube (Dc = 16.59 mm) with the tube row ranging from 1 to 16. It is found that the effect of tube row on the heat transfer performance is quite significant, and the heat transfer performance deteriorates with the rise of tube row. The performance drop is especially pronounced at the low Reynolds number region. Actually more than 85% drop of heat transfer performance is seen for Fp _ 1.7 mm as the row number is increased from 1 to 16.

IV. CONCLUDING REMARKS OF LITERATURE REVIEW

1. According to the literature available on the " Herringbone wavy fin & Smooth wavy fin" we conclude that there are research papers available on the various types of Heat exchangers, Analysis part of heat exchanger & performance of heat exchangers
2. Hence it shows that very few researches is available on the optimum performance of study on Herringbone & smooth wavy fin.
3. Hence it clears that there is a wide scope for work on new analysis of performance of herringbone wavy fin & smooth wavy fin heat exchanger

V. RESEARCH OBJECTIVES

1. To Design and fabrication of Herringbone wavy fin structure module
2. To Design and fabrication of Smooth wavy fin structure module
3. To develop &testing of the wavy fin enhanced cross flow hydraulic oil cooler individual on test rig

Wavy Fin Heat Exchanger:

Two basic geometries of wavy fin; (a) herringbone or corrugated passage, (b) smooth passage.

Wavy fins are one of the most popular heat exchanger surfaces since it can lengthen the airflow inside the heat exchanger and improve mixing of the airflow. Hence, wavy fin-and-tube heat exchangers are extensively employed in various industrial applications. They are quite compact and characterized by a relatively low cost fabrication. In case of wavy plate fin-and-tube heat exchangers, a liquid flows through the tubes and a gas (usually air) flows through the channels formed by the neighboring, parallely placed wavy fins around the tube banks. Figure shows the three-dimensional view of a wavy plate fin-and-tube heat exchanger. The tubes are placed in either staggered or in-lined layout.

The wavy fin extended surfaces are recognized by the peculiar corrugations which enhance the heat transfer performance in comparison to the plain plate surfaces. For a corrugated geometry having constant corrugation angles and sharp wave tips, the key parameters that affect the heat transfer performance are the wavy pitch, the corrugation angle and the fin spacing. In case of wavy fins the boundary layer is repeatedly interrupted as the flow passes over the corrugations, this redeveloping of the boundary layer from the reattachment point of the last wavy corrugation contributes to the heat transfer enhancement.

VI. DESIGN AND DEVELOPMENT OF SYSTEM

A) Heat Exchanger Cooling

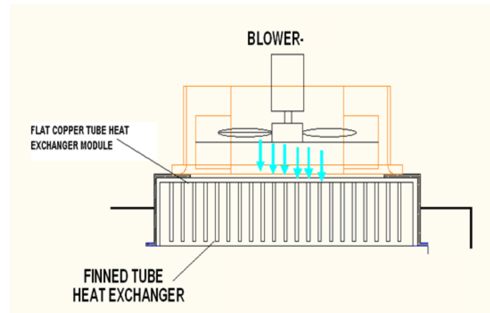


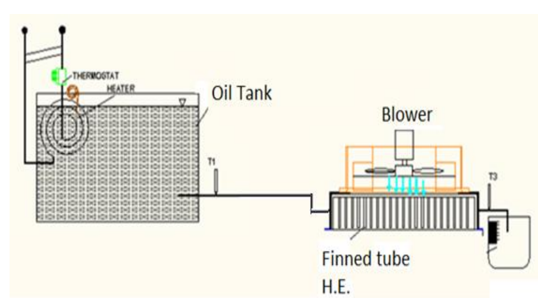
Fig. 2 Cooling Arrangement of Fin

B) Details of the individual fin structure modules are as follows:

Herringbone wavy fin

Smooth wavy Fin

C)Layout of Experimental Setup:



VI.- RESEARCH SETUP

A) Experimental Investigation

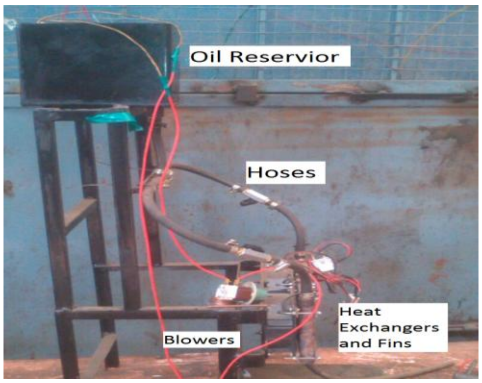
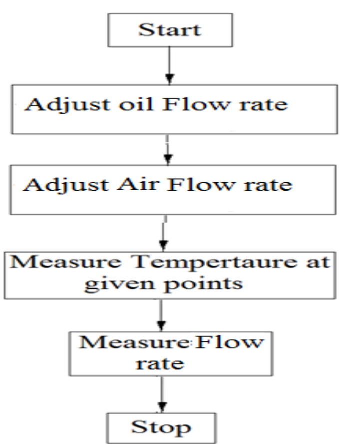


Fig. 3 Experimental set-up

In this research work, the investigation is made on the heat transfer with herringbone wavy and smooth wavy fins in oil cooling process. Experimental setup used for this dissertation work has been shown in this figure. This fig. shows all the components and their connections with each other.

B) Experimental Procedure



VII. OBSERVATIONS

Setting Up Constant Discharge for Air

Discharge of Air:- Table:-7.1

Sr. No.	Manometer Reading (H_1) (in cm)	Manometer Reading (H_2) (in cm)	H (in cm)	Discharge LPS
1	8.3	8.1	0.2	0.001507
2	8.45	8.2	0.25	0.001685
3	8.4	8.1	0.3	0.001846

Observations for Herringbone wavy fins:

Mean mass flow rate:0.001145kg/sec:

Table 7.2 Observations for Herringbone wavy Fins

Sr.No.	Hot Oil Inlet Temp. (T_{Hi}) in ⁰C	Hot Oil Outlet Temp (T_{Ho}) in ⁰C	Air inlet Temp. in ⁰C	Air outlet Temp. in ⁰C
1.	48	40	27	29.5
2.	49	41	27	29.4
3.	48	41	26	28.6

Mean mass flow rate: 0.001269 **kg/sec**

Table 7.3 Observations for Herringbone wavy Fins

Sr.No.	Hot Oil Inlet Temp. (T_{Hi}) in ^0C	Hot Oil Outlet Temp (T_{Ho}) in ^0C	Air inlet Temp. in ^0C	Air outlet Temp. in ^0C
1.	48	39	26	29
2.	49	38	25	28.2
3.	48	38.5	25	28

Mean mass flow rate: 0.001323 **kg/sec**

Table 7.4 Observations for Herringbone wavy Fins

Sr.No.	Hot Oil Inlet Temp. (T_{Hi}) in ^0C	Hot Oil Outlet Temp (T_{Ho}) in ^0C	Air inlet Temp. in ^0C	Air outlet Temp. in ^0C
1.	48	34	28	31.8
2.	48	34.4	28	31.7
3.	49	34.2	28	31.8

OBSERVATIONS FOR SMOOTH WAVY FINS:

Mean mass flow rate: 0.001145kg/sec

Table 7.5 Observations for Smooth wavy Fins

Sr.No.	Hot Oil Inlet Temp. (T_{Hi}) in ^0C	Hot Oil Outlet Temp (T_{Ho}) in ^0C	Air inlet Temp. in ^0C	Air outlet Temp. in ^0C
1.	40.5	37.5	25	27.6
2.	49	39.5	25	27.1
3.	48	39	26	28.4

Mean mass flow rate: 0.001269 **kg/sec**

Table 7.6 Observations for Smooth wavy Fins

Sr. No.	Hot Oil Inlet Temp. (T_{Hi}) in ^0C	Hot Oil Outlet Temp (T_{Ho}) in ^0C	Air inlet Temp. in ^0C	Air outlet Temp. in ^0C
1.	48	37	26	28.9
2.	49	36.6	25	28.2
3.	48	36.1	25	28

VII RESULTS AND DISCUSSIONS

<u>Results for Herringbone Wavy Fins</u>

I)Mean mass flow rate: 0.001145 kg/sec

Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^0C)	Temperature Difference between Air inlet and outlet (θ in ^0C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m^2k)
1	8	2.5	0.0172	0.571
2	8	2.4	0.0172	0.5948
3	7	2.6	0.0150	0.4804

II) Mean mass flow rate: 0.001269 kg/sec

Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^0C)	Temperature Difference between Air inlet and outlet (θ in ^0C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m^2k)
1	9	3	0.0214	0.5933
2	11	3.2	0.0262	0.6798
3	9.5	3	0.0226	0.6263

III) Mean mass flow rate: 0.001323 kg/sec

Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^{0}C)	Temperature Difference between Air inlet and outlet (θ in ^{0}C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m²k)
1	14	3.8	0.0347	0.7596
2	13.6	3.7	0.0337	0.7579
3	14.8	3.8	0.0367	0.803

Results for Smooth Wavy Fins

I)Mean mass flow rate: 0.001145 kg/sec

Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^{0}C)	Temperature Difference between Air inlet and outlet (θ in ^{0}C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m²k)
1	9	2.6	0.0185	0.2059
2	9.5	2.1	0.0204	0.8072
3	9	2.4	0.0193	0.6692

II) Mean mass flow rate: 0.001269 kg/sec

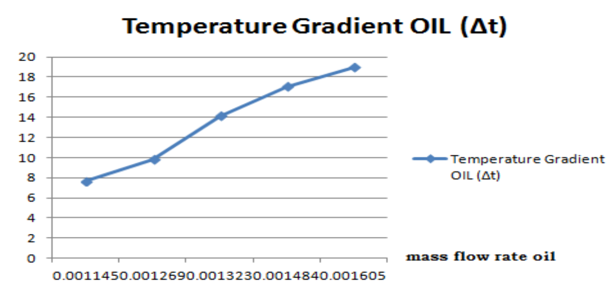
Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^{0}C)	Temperature Difference between Air inlet and outlet (θ in ^{0}C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m²k)
1	11	2.9	0.0262	0.7501
2	12.4	3.2	0.0295	0.7663
3	11.9	3	0.0283	0.7845

III) Mean mass flow rate: 0.001323 kg/sec

Sr. No.	Temperature Difference between oil inlet and outlet (ΔT in ^{0}C)	Temperature Difference between Air inlet and outlet (θ in ^{0}C)	Heat Transfer From Oil (Q in kW)	Heat Transfer Coefficient (U in kW/m²k)
1	16	3.6	0.0396	0.9163
2	15.6	3.6	0.0386	0.8934
3	15.8	3.8	0.0391	0.8573

VIII DISCUSSIONS.

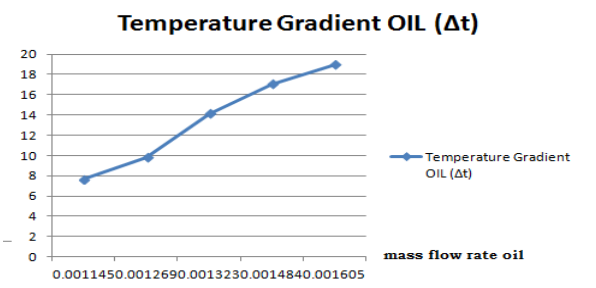
Oil Temperature Gradient Vs Mass Flow Rate in Smooth Wavy Fins



Graph 8.1 Temperature Gradient Vs Mass flow rate

Graph 8.1 shows the change in temperature of hot oil with respect to increasing mass flow rate. It can be observed that with increase in mass flow rate of oil temperature gradient of oil also increases. When mass flow rate of oil increases quantity of oil flowing through heat exchanger tubes also increases hence heat from oil will be transferred to the tube walls which will lead to decrease in temperature at the outlet. When less mass flows through the tubes area available for heat transfer from oil to tube wall will decreases and cooling of hot oil will be less. From this graph it can be observed that when mass flow rate increases from 0.001145 to 0.001605 temperature gradient also increases from 9^{0}C to 21^0 C.

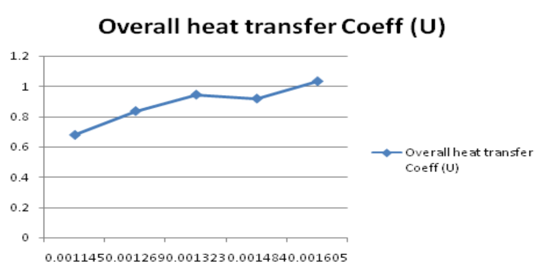
Oil Temperature Gradient Vs Mass Flow Rate in Herringbone Wavy Fins



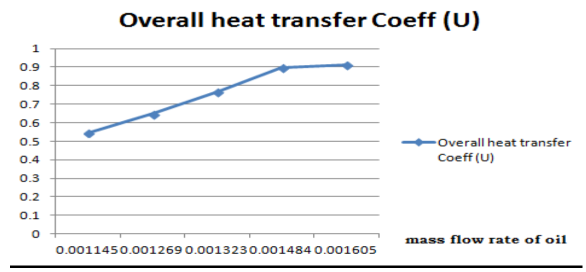
Graph 8.2 Temperature Gradient Vs Mass flow rate

It can be observed from graph 8.2 that the temperature gradient of oil will increase with increase in mass flow rate in heat exchanger equipped with herringbone wavy fins. From graph 6.12 it can be observed that at 0.001145 mass flow rate the temperature gradient is 8^0C and when mass flow rate increases up to 0.001605 temperature gradient increases to 19^0C

Overall heat transfer Coefficient Vs Mass Flow Rate in Smooth Wavy Fins



Overall heat transfer Coefficient Vs Mass Flow Rate in Herringbone Wavy Fins



IX CONCLUSIONS.

Based on the results obtained in this investigation, the following conclusions are made:

[1] In this work amount of heat transferred from heat exchanger with herringbone wavy fin and smooth wavy has been investigated and studied. In this study it is seen that the amount of heat transferred in case of smooth wavy fin is more than that of in herringbone fin heat exchanger. Maximum 28% enhancement in heat transfer has been observed from heat exchanger in herringbone wavy fin case as compared to smooth wavy fins.

[2] In this work also heat transfer coefficient of both herringbone wavy fin and smooth wavy has been investigated, compared and studied. From comparison it is find out that the heat transfer coefficient of the smooth wavy fin heat exchanger is maximum 38% higher than herringbone wavy fin heat exchanger.

On average 13.37% increase in smooth wavy fin heat exchanger has been observed when compared to the herringbone wavy fin heat exchanger.

[3] The cooling of oil is efficient in the case of smooth wavy fins it is observed that in case of herringbone wavy fin heat exchanger temperature decrease in oil is maximum 19.9^0C and in case of smooth wavy fin heat exchanger it is 21.9^0C.

On average decrease in temperature of hot oil when it is passed through the heat exchanger is 13.5^0C for herringbone wavy fin heat exchanger and 14.87^0C for herringbone wavy fin heat exchanger.

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