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EXPERIMENTAL STUDY OF HEAT TRANSFER & PRESSURE DROP IN A SPIRAL GROOVED TUBE WITH RECTANGULAR COPPER FIN AT DIFFERENT PITCHES

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ABSTRACT

In this manuscript we have analyzed the Air-Cooled Heat Exchanger (ACHE) with test setup with internal spiral grooving in variation of pitches, this work also compares the performance of simple tube without grooving with grooved tube, all of the test setup are having variable pitches viz. 5 mm grooving, 10 mm grooving and 15 mm grooving respectively. In the test setup average heat transfer rate of a counter to cross flow ACHE for natural convection are 3010 watt, 3058 watt, 3078 watt and 3112 watt for simple tube without grooving, tube with 15 mm grooving pitch, tube with 10 mm grooving pitch and tube with 5 mm grooving pitch respectively. Similarly, for forced convection rate of average heat transfer are 3044 watt, 3063 watt, 3099 watt and 3146 watt for simple tube without grooving, tube with 15 mm grooving pitch, tube with 10 mm grooving pitch and tube with 5 mm pitch distance respectively. In the test setup effectiveness (in percentage) of the heat exchanger of 5 mm grooving pitch , 10 mm grooving pitch , 15 mm grooving pitch and simple tube without grooving are 7.072 , 6.960 , 6.870 and 6.715 respectively. In the test setup average Reynold Number of the air cooled heat exchanger of 5 mm grooving pitch, 10 mm grooving pitch , 15 mm grooving pitch and simple tube without grooving are 24135.42 , 19803.47 , 16863.85 and 14232.56 respectively. In the test setup average Nusselt Number of the air cooled heat exchanger of 5 mm grooving pitch , 10 mm grooving pitch , 15 mm grooving pitch and simple tube without grooving are 95.68 , 81.67 , 71.82 and 62.71 respectively. In the test setup average pressure drop (in N/mt2) of the ACHE of 5 mm grooving pitch , 10 mm grooving pitch , 15 mm grooving pitch and simple tube without grooving are 0.05004, 0.03501 , 0.02674 and 0.0199 respectively.

Keywords: Rate of heat transfer, Effectiveness, Thermal efficiency, Spiral grooving, Rectangular Fins, Capacity Ratio, Number of Transfer Unit (NTU), Reynold Number, Pressure Drop.

INTRODUCTION

A heat exchanger is a device used to transfer heat between two or more fluids. Thefluids can be single or two phase and, depending on the exchanger type, may be separated or in direct contact. It transfers thermal energy at different temperatures.Depending on the type of heat exchanger employed, the heat transferring process can be gas-to-gas, liquid-to-gas, or liquid-to-liquid and occur through a solid separator, which prevents mixing of the fluids, or direct fluid contact. In heat exchangers, there are usually no external heat and work interactions.

Turbulence in the flow of fluid and rectangular copper fins are used to increase the overall surface area of heat exchangers and hence increase the heat transfer rate. It is evident form different research, it's a known fact that grooving is an efficient method to increase the rate of heat transfer. It is also understood from the above literature that no study was performed on the thermal behavior of two similar grooved tubes when the grooving pitches between them is changed. Hence, experimental work was carried out to check the thermal improvement and optimum pitches between the tubes to be kept for efficient heat transfer. In this study, three internal spiral grooved tubes with a pitch of grooving are 5 mm, 10 mm and 15 mm pitch, so far as we are talking about type of grooving, we consider spiral tubular type grooving rather than rectangular grooving as spiral tubular grooving has much better in term as of performance parameter . In the test setup we are taking two setup first with natural convection and second with forced convection for three different pitch of grooving viz. 5 millimeters grooving , 10 millimeters grooving and 15 millimeters grooving and observed the various performance parameters. The observation is again compares with simple heat exchanger without grooving the result of comparisons evident the fact of heat transfer rate improves with grooving without degrading any other performance parameters.

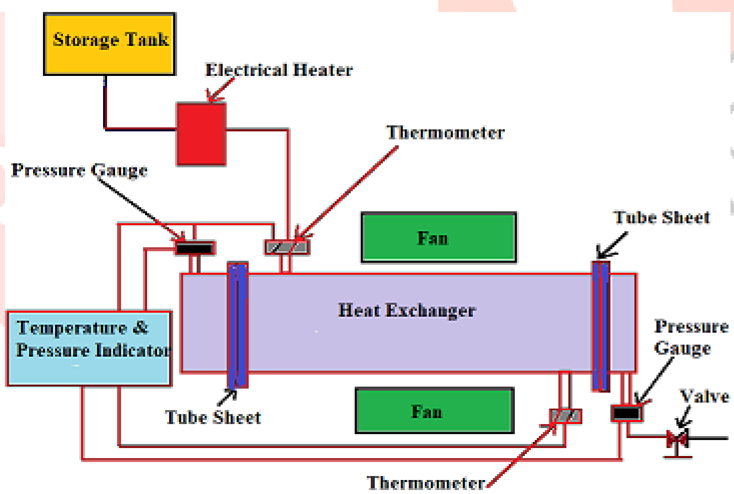

Figure 1. Block diagram of experimental set-up for forced convection in Air Cooled Heat Exchanger.

A heat exchanger is Heat exchangers are one of the generally utilized supplies in the process enterprises. Heat exchangers are utilized to move heat from one fluid to another fluid.

Classification of Heat Exchanger

- Direct and indirect contact type
- Based on the number of fluids
- Based on the flow arrangement
- Based on heat transfer mechanism
- Regenerator and recuperate

II. LITERATURE REVIEW

Chang, Tae-Hyun et al. [1] studied thermal performance and pressure drop are considered as major factors. Both, thermal performance and pressure drop are dependent on the path of fluid flow and types of baffles in different orientations respectively. Increasing the complexity of baffles enhances heat transfer which also results in higher pressure drop which means higher pumping power is required. This reduces the system efficiency.

Afzal et al. [2] experimentally studied the optimum spacing between grooved tubes is reported in this paper. Two grooved tubes having pitch of 10 mm and 15 mm and a plain tube were considered for the heat transfer analysis. The spacing between two tubes with same pitch was varied from 10 mm to 35 mm with a step size of 5 mm. Velocity of air flowing over the tube surfaces was changed from 0.4 m/s to 1 m/s using a blower fan. Based on Nusselt number (*Nu*) the optimum spacing between the tubes was decided. The optimum spacing between grooved tubes of pitch 10 mm and 15 mm was compared with that of plain tubes.

S Basavarajappa et al. [3] Experiments investigated the effect of nanofluid on turbulent heat transfer and pressure drop inside concentric tubes. Water and SiO_2 with mean diameter of 30 nm were chosen as base fluid and nano-particles, respectively. Experiments were performed for plain tube and five roughened tube with various heights and pitches of corrugations.

Hassan Jafari Mosleh et al. [4] experimentally and numerical investigated the pulsating heat pipes(PHPs) as substitutes for fins in a representative air-cooled heat exchanger(ACHE).Because of low temperatures difference between the cooling air and internal airflow. In which R134a was selected as the best working fluid from the heat transfer stand point. Than PHPs are filled with working fluid, the coefficient of heat transfer and temperature difference have been increased.

Jian Wang et al. [5] experimentally studied the heat transfers and flow individuality of the three new finned copper head heat sinks are subjected to the impingement chilled by rectangular slot jet and axial fan. These experimental process are used for the fast development of electronic devices has imposed higher requirements for thermal supervision and cooling technology. In this experiment taken effect of heat sink heights (H, 15, 30, 45, 60 mm), the pore density of the inserted copper head (PPI, 10, 20, and 30) and the gas flows Reynolds number(*Re*, varying from 2053- 12737) are scientifically investigated..

Demis Pandelidis et al. [6] studied the sloping evaporative exchangers are worked as heat recovery units, given configurations are counter flow and cross flow. In this experiment presented analysis are accepted out with particular importance on the condensation process that occurs in the product air channels of the exchangers. In which various aspects are related to the water vapor condensation and manage. Which aspects are taken in the classification factors that control the condensation process. Those analyzing factors are forced on dissimilar IEC exchanger arrangement. There are a variety of inlet parameter and operating condition for judgment of the counter and cross flow exchangers. Those performed analysis are based on numerical simulations with mathematical e-NTU models of heat and mass transfer.

Nithiyesh Kumar et al. [7] experimentally studied the flow over array of trapezoidal-ribs transversely placed on the wider bottom surface of the rectangular passage. It is intended to study the profound impact of taper angle variation (0 to 20°) on the flow mechanism, and subsequently on heat transfer improvement. The local and augmentation heat transfer patterns have been investigated using liquid crystal thermography (LCT). Further, the aerodynamic characteristics, in a module between seventh and eight ribs, have been obtained using particle image velocimetry (PIV) for understanding the flow physics. Existence of large- and small-scale coherent structures within the detached shear layer zone have been confirmed and further explained by means of critical points. As compared to square rib, trapezoidal rib provides higher heat transfer rate just downstream of the rib, which is observed to be in line with the fluid flow results.

Pengxiao Li et al. [8] experimentally investigated the thermal performance and exergy analysis in an internally grooved (IG) tube fitted with triangular cut twisted tape insert consisting of alternate wings (TCTT). The analysis is carried out with TCTT for different twist ratio, y = 3.5, 5.3 and 6.5 with attack angle, β = 45° and 90°. The investigations were performed in turbulent regime, with Reynolds number ranging from 3000 to 14,000. The thermal and exergy efficiencies were used to evaluate the overall performance of the heat exchanger, by considering exergy gain and exergy lost.

Pankaj N. Shrirao et al. [9] experimentally studied the mean Nusselt number, friction factor and thermal enhancement factor characteristics in a circular tube with different types of internal threads of 120 mm pitch under uniform wall heat flux boundary conditions. In the experiments, measured data are taken at Reynolds number in range of 7,000 to 14,000 with air as the test fluid. The experiments were conducted on circular tube with three different types of internal threads viz. acme, buttress and knuckle threads of constant pitch. The heat transfer and friction factor data obtained is compared with the data obtained from a plain circular tube under similar geometric and flow conditions..

Bayram Sahin et al. [10] Study design parameter of a heat sink on which hollow trapezoidal baffle is mounted on the base surface. This experimental design is used Taguchi method. Where Nussle numbers and friction factors are considered as performance parameter. In which orthogonal arrays are selected as investigational plan for the six parameters: the curve angles(α), the inclination angle (β), the baffle heights(H), the baffle lengths(L), thebaffle width(S) and Reynolds numbers. First of each goal has been optimized individually and after that all the goals have been optimized together. The baffle lengths(L) are found on the friction factor. The baffle length will in flow direction .Where are the best parameters on the exchange warmth is Reynolds number. The result showed that the heat transfer was obtained at Re=17,000, H=36 mm, L=45 mm, S=26 mm, α=0°, β=0°. It can be conclude higher heat transfer rates are achieved with lower pressure drop.

III. MODIFICATIONS IN TEST SETUP

In this section, we are discussing the test setup design of copper fins and variation of different spiral grooving at different pitches.

3.1 Fin Dimension for the Counter to Cross Flow Air Cooled Heat Exchanger

The fin dimension of test setup of the rectangular fin of thickness 0.5 mm height of the fin is 6.4 centimeter and characteristic length, which is equal to 11.2 centimeters. These dimensions are basically calculated with the help of standard formula and the layout of the of design is shown in figure 2

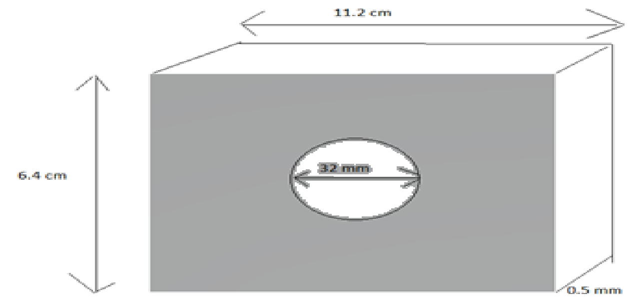

Figure 2: Layout of rectangular copper fin of test setup in counter to cross air cooled heat exchanger.

3.2 Simple Tube Dimension for the Counter to Cross Flow Air Cooled Heat Exchanger

In air cooled heat exchanger simple tube dimension are taken outer diameter of 32 mm, with internal diameter of 26 mm as shown below (fig. 4). The overall characteristics length of the proposed tube is 1 meter standard dimension. Fig. 4 gives a layout of simple tube without any grooving. Tube material is aluminium its thermal conductivity is 240 w/mt.k ,it is lighter in weight and flexible.

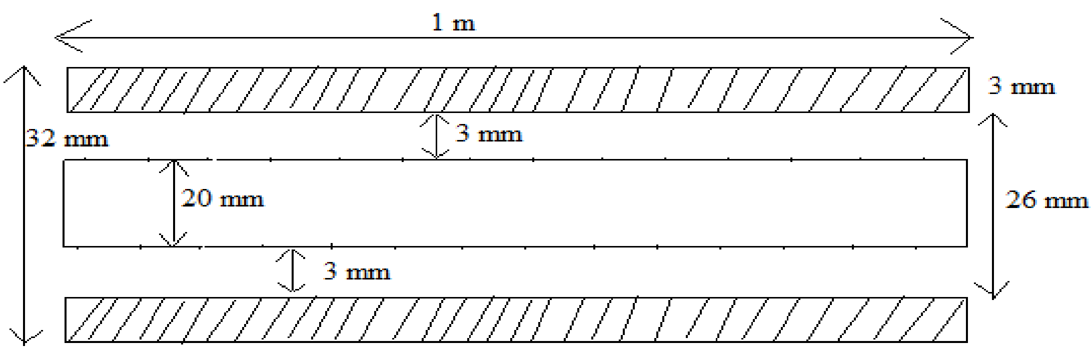

Figure 4: Layout of simple tube without grooving air cooled heat exchanger

3.3 Internal Spiral Grooving Tube Dimension for the Counter to Cross Flow Air Cooled Heat Exchanger

In this test setup we compare with simple tube with grooving tube at different pitches, and analyzed heat exchanger parameters which gives better performance simple tube or grooved tube, if grooved tube gives better result then we analyzed which pitch sizes are more efficient. In simple tube analysed in free and force both convection of heat transfer and pressure drop of heat exchanger.

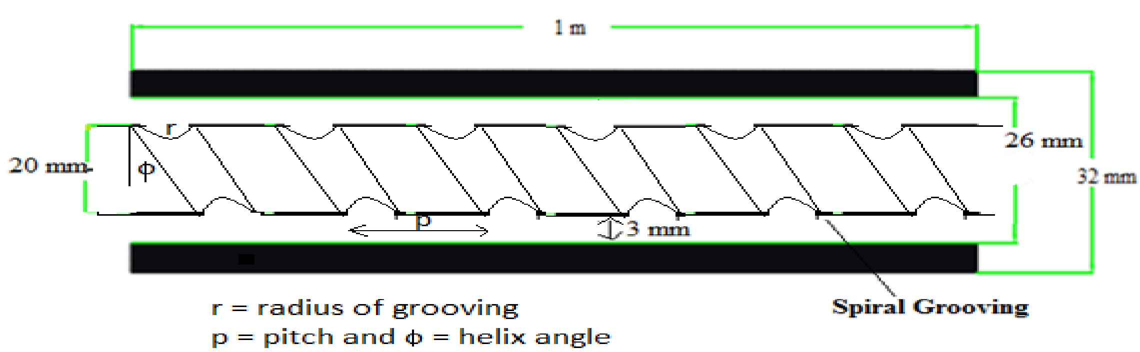

Figure 4: Layout of heat exchanger with internal spiral grooving tube

In the test setup design the variation of pitches are used to analyzed which design perform better in term of heat transfer rate we are also using copper fins further to observe the same parameters in both forced convection as well as in natural convection for 5 mm grooving, 10 mm grooving and 15 mm grooving pitches three test setup for the ACHE. The internal structure of the test setup heat exchanger is shown with the help of Fig. 4, here "p" represents the variation of pitch (in mm) used for different test setup. "r" represent radius of grooving and "φ" represent helix angle of internal spiral grooving.

3.4 Modified Physical Test Setup of the Counter to Cross Air Cooled Heat Exchanger

We are designed internal spiral grooving with rectangular copper fin, material of tube aluminium and fin are copper, then finally we designed the heat exchanger outer structure. Our proposed heat exchanger is air cooled heat exchanger with counter to cross condition , then we decided to aerodynamics shape of the our setup. The test physical setup is shown in fig.5 as well.

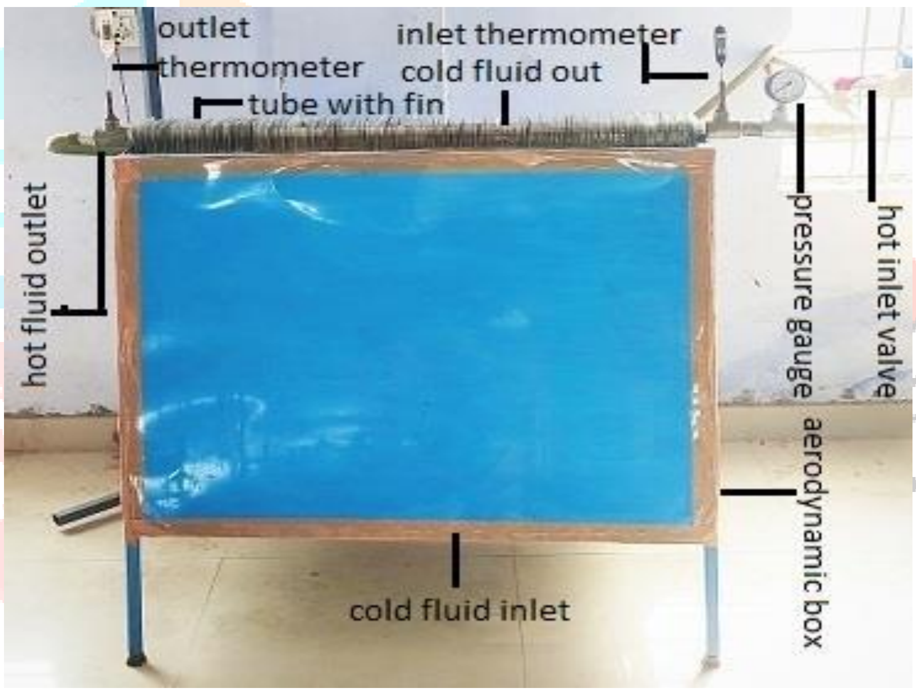

Figure 5: Physical setup for heat exchanger with internal grooving with fin of air cooled heat exchanger

IV. RESULTS AND DISCUSSION

This section is devoted to the result calculated for the test setup of three variations of pitches in Air-Cooled Heat Exchanger (ACHE) design with internal spiral grooving. The calculation of various Parameters starts with the calculation of discharge through the internally grooved tube.

4.1 Analysis of Heat Transfer Rate of a Counter to Cross Flow for Air Cooled Heat Exchanger

which setup are better .the heat transfer rate of heat exchanger without fan are as 3132 watt , 3078 watt , 3058 watt , and 3010 watt of the test setup are 5 millimeters grooving, 10 millimeters grooving , 15 millimeters grooving , and simple tube (without grooving) respectively. The heat transfer rate of heat exchanger with fan are as 3146 watt ,3099 watt, 3063 watt, and 3044 watt of the test setup are 5 millimeters grooving , 10 millimeters grooving , 15 millimeters grooving , and simple tube (without grooving) respectively.

Table I: Heat transfer rate of a counter to cross flow ACHE for test setup.

S No.	Grooving Pitch	Max. Heat TransferRate Natural Convection	Max. Heat TransferRate Forced Convection
1.	05 mm	4206.29 watt	4234.16 watt
2.	10 mm	4145.26 watt	4163.96 watt
3.	15 mm	4122.06 watt	4141.47 watt
4.	Simple tube Without grooving	4106.101 watt	4125.42 watt

In the heat exchanger we analyzed the heat transfer rate of free convection and force convection at different pitches such as 5 millimeters, 10 millimeters and 15 millimeters of grooving tube and without grooving tube.

4.2 Effect of Fluid Temperature on Heat Transfer Rate at Different Pitch for Air Cooled Heat Exchanger

The effect of fluid temperature on heat transfer rate at different pitch that is 05mm, 10mm, 15mm, 20mm internal spiral grooving tube and simple tube (without grooving) of a counter to cross flow air cooled heat exchanger for free and forced convection is shown Fig. 4.1 and Fig. 4.2 respectively.

4.2.1 Effect of Fluid Temperature on Heat Transfer Rate at Different Pitch for Air Cooled Heat Exchanger for Free Convection

The variation of heat transfer rate and temperature at different pitch of a counter to cross flow air cooled heat exchanger for free convection is shown Fig. 4.1

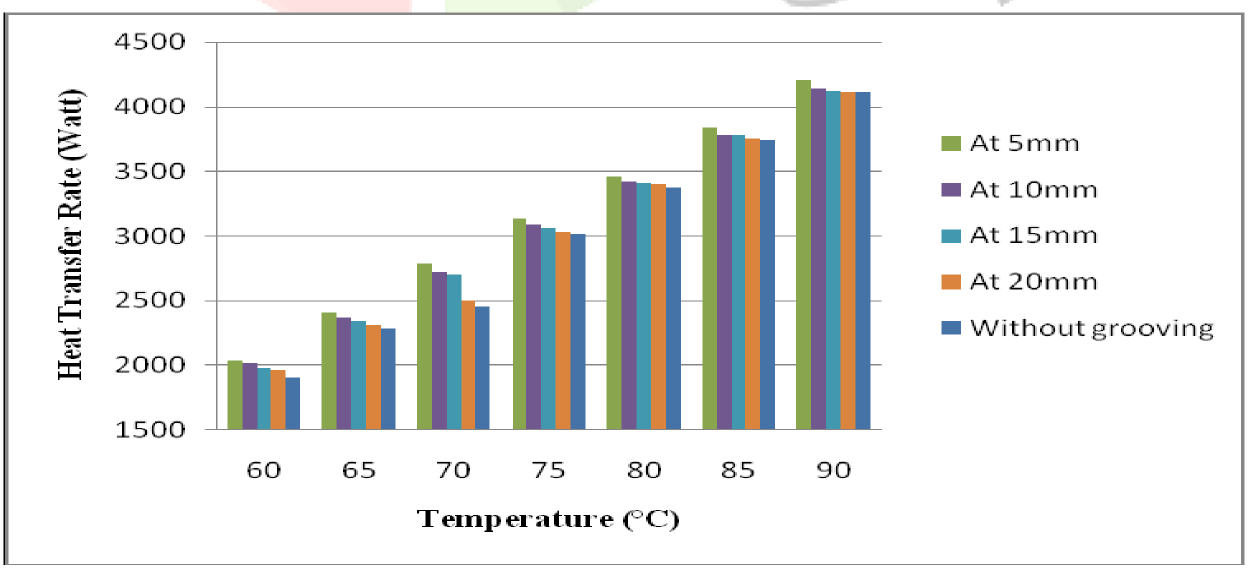

Fig. 4.1 Effect of fluid temperature on heat transfer rate at different pitch for air cooled heat exchanger for free convection

From the experimental investigation it was observed that heat transfer rate increased with increase in temperature. It was found that heat transfer rate increases with decrease in pitch that is distance of internal spiral grooving. Also it was observed that heat transfer rate was more for internal spiral grooving than simple tube without grooving. This behavior can be attributed to fact that closer pitch size of grooves on the tube surface enhances the convective heat transfer coefficient which further increases the rate of heat transfer [11]. Further maximum heat transfer rate was observed at 5mm pitch (internal spiral grooving).

4.1.2 Effect of Fluid Temperature on Heat Transfer Rate at Different Pitch for Air Cooled Heat Exchanger for Forced Convection

The variation of heat transfer rate and temperature at different pitch of a counter to cross flow air cooled heat exchanger for forced convection is shown Fig. 4.2.

From the experimental investigation it was observed that heat transfer rate increased with increase in temperature. It was found that heat transfer rate increases with decrease in pitch that is distance of internal spiral grooving. Also, it was observed that increased heat transfer rate was obtained for forced convection as compare to free convection. This is attributed to fact that with the increase in spacing between the tubes the change in temperature of tube surface decreases [11]. Furthermore maximum heat transfer rate was observed at 5mm pitch (internal spiral grooving).

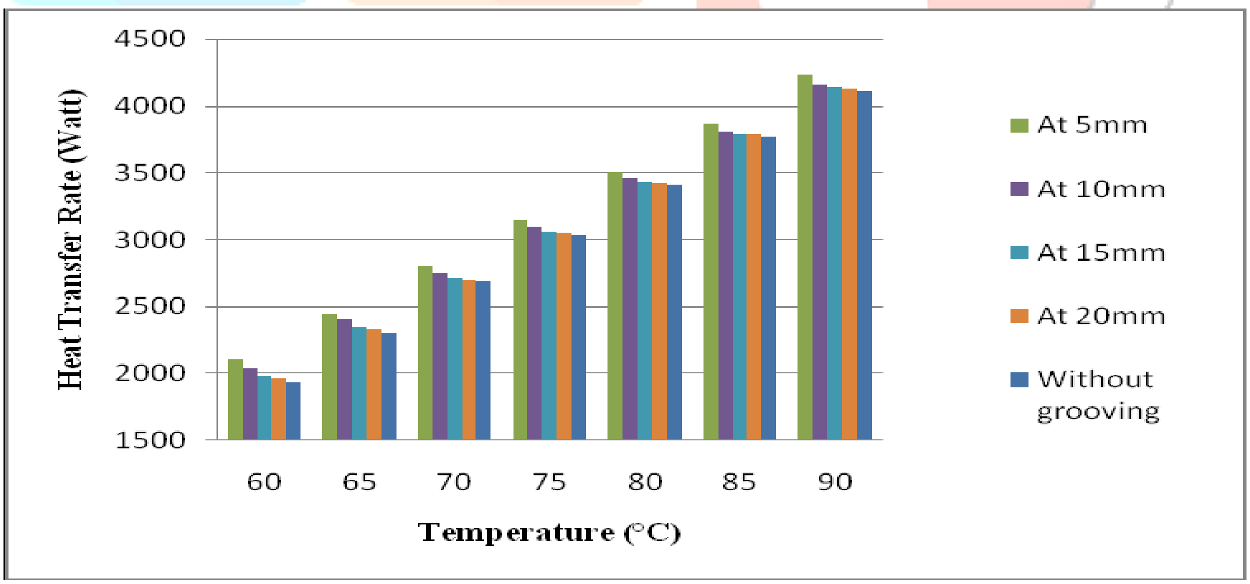

Fig. 4.2 Effect of fluid temperature on heat transfer rate at different pitch for air cooled heat exchanger for forced convection

4.5 Experimental Analysis of Effectiveness of Air Cooled Heat Exchanger at Different Pitch

The variation of effectiveness of a counter to cross flow air cooled heat exchanger at different pitch is shown Fig. 4.3

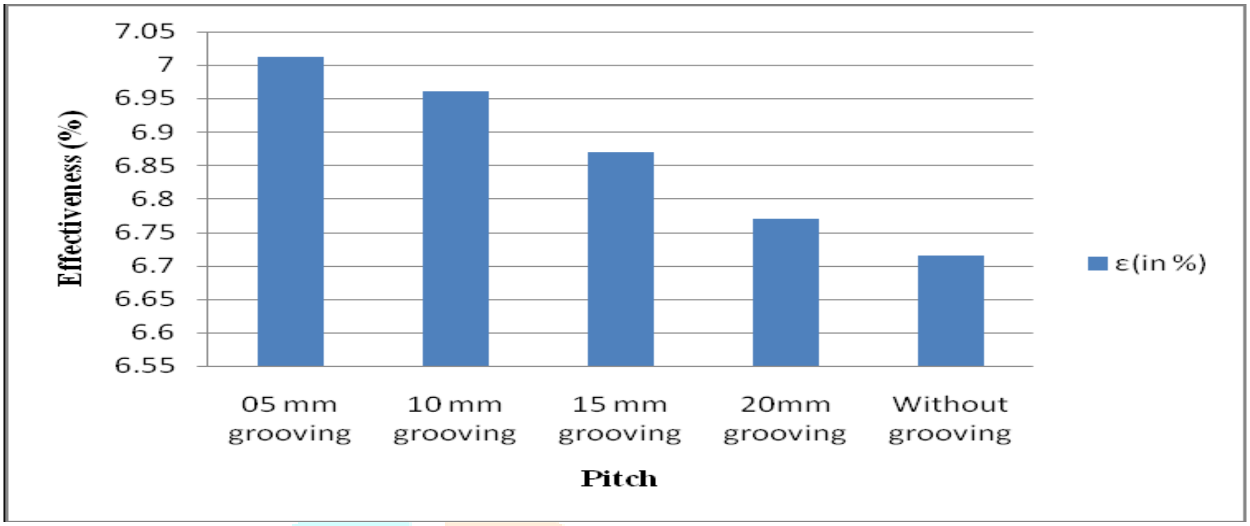

Fig. 4.6 Effectiveness of Air Cooled Heat Exchanger at Different Pitch

Fig. 4.3 shows that decrease in heat exchanger effectiveness was observed with increase in pitch that is distance of internal spiral grooving. Also it was observed that heat exchanger effectiveness was more for internal spiral grooving than simple tube without grooving. The above mentioned analysis that making internal grooves in the tube with appropriate pitch size may increase the heat transfer rate which further increases the heat exchanger effectiveness. Similar facts were previously reported by researchers [11].

V. CONCLUSIONS

This experimental study examined and analyzed the various internal Spiral grooving heat exchangers at different pitches with rectangular copper fins. Key findings from this study are as follows:-

1. The heat transfer rate increases with increase in temperature at different pitch of internal spiral grooving. It was found that heat transfer rate increases with decrease in pitch that is distance of internal spiral grooving. Also, it was observed that increased heat transfer rate was obtained for forced convection as compare to free convection.

2. Increased Reynolds number was obtained for different pitch of internal spiral grooving at different temperature. it was found that Reynold number increases with decrease in pitch that is distance of internal spiral grooving. This shows that the turbulence formation advanced due to artificial turbulence exerted by internal spiral grooving. This increases the swirl flow across the range of Reynolds numbers.

3. With increase in Renolds number the Nusselt number also increases irrespective of tubes with and without grooves. This is mainly due to increase in convective heat transfer coefficient of fluid flowing between the tubes.From the experimental investigation it was reported that Nusselt number increased with increase in temperature. Also it was found that Nusselt number increases with decrease in pitch that is distance of internal spiral grooving.

4. The heat transfer rate has the increasing trend with the rising of the temperature. Conversely, the pressure drop decreases. Also it was found that pressure drop increases with decrease in pitch that is distance of internal spiral grooving. Further maximum pressure drop was observed at 5mm pitch (internal spiral grooving). the rising temperature causes the fluid viscosity to decrease and the pressure drop of the heat exchanger then reduces. And the heat transfer rate has the trend increasing with the rising of the average temperature. Conversely, the pressure drop decrease.

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