Research Paper

Effects of Corrugation Profile on the Heat Transfer Rate of Fins

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Abstract

Heat is a form of energy that can be transformed from one form to another. Practically, heat transfer can exist only when there is a temperature gradient between two substances. The heat transfer phenomenon takes place in three modes, conduction in solids, convection in fluids and radiation through any medium that permits radiation to pass. Fins are used in many kinds of applications to increase the rate of heat transfer from surface area and to provide cooling effects. The fin material has a high thermal conductivity. Heat transfer from the surface of the fin to the surrounding atmosphere is mainly due to convection. Corrugated profiles are very important for convective heat transfer in many engineering applications. Studies and investigations on convective heat transfer in corrugated channels have been carried out using water or air as a working fluid. In this project, the impact of corrugated fin on heat transfer performance is considered as the topic of study. Angular fin is compared with flat fin. Computational simulations were carried out using ANSYS 14.0 FLUENT software and for experimental section, it was done using Heat Transfer Convection Trainer (Model: TERA-CT-115). Both experimental and simulation results revealed the improved heat dissipation in the corrugated fins compared to the flat fins.

Keywords:-Heat dissipation, fin, corrugated shape.

1 Introduction

Heat is defined as energy in travel due to temperature difference. Heat transfer is amongst the most ubiquitous processes in nature. It is even an inevitable process within virtually all machines, devices and instruments. With such a wide scope of application, heat transfer turns into a key part of engineering knowledge base. Heat exchanger is defined as a device permitting the transfer of thermal energy between solid particulates and a fluid, two or more fluids, a fluid and a solid surface at diverse temperatures and thermal contacts. Heat exchangers are not merely used in the procedures for air-conditioning, cryogenic, alternative fuel, refrigeration, petroleum, power heat recovery, nor manufacturing industries. It is also a key function in market availability of many industrial products [1].

A fin material should have a high thermal conductivity; while having a large surface area, fins could carry the heat developed in the application to be carried to the fin surface. Fins exposed to surrounding fluids promote higher convective heat transfer.

A large number of engineering applications use fins to increase the heat transfer rate such as single-double cylinder IC engines, radiators in cars, air-conditioning equipment, refrigerators and CPU heat sinks in the computers. The larger the surface area the greater is the amount of heat transferred. Hence, fins and corrugated profiles are high-efficiency heat transfer structures.

According to Newton's Law of cooling, the heat transfer rate is given by the equation

$$q = hA\,(T_s - T_f) \qquad (1)$$

Where, q is the heat transfer rate in W, h is the convection heat transfer coefficient in W/m^{2}K, A is the surface area through which convection heat transfer takes place in m^2, T_3 is the surface temperature, and T_f is the temperature of the fluid sufficiently far from the surface in K[2].

Above equation 1 states that the heat transfer rate is mainly dependent on the heat transfer coefficient (h) and surface area (A). In order to increase the heat transfer rate, it is obvious to increase either surface area A or heat transfer coefficient h. To Increase h, it would require a high capacity pump or blower because h is a function of coolant velocity. Installing a high capacity pump or blower would be an expensive option. Another way to increase the heat transfer is to increase the surface area of the fins.

Corrugated plate fins have a larger heat transfer surface area and increased turbulence level due to the corrugations. Jogi et al have analyzed the corrugated plate heat exchanger experimentally. Based on their experimental data they proposed a simplified Nusselt number correlation incorporating effects of Reynolds number, Prandtl number, viscosity variation and chevron angle(β) [3]. Tisekar et al have analyzed the performance of corrugated plate heat exchanger with water as a working fluid. It has been found that corrugated plate type is much more efficient than tube type heat exchanger [4]. Khoshvaght et al has studied the thermal-hydraulic characteristics of plate-fin heat exchangers with corrugated/ vortex- generator plate- fin (CVGPF). In this work a new design of the plate fin of corrugated and vortex has been designed. Further, the hydraulic performances of all plate-fins improved as the mass fraction of ethylene glycol in the working fluid increases [5]. Zhao-gang et al have done the parametric study on the performance of a heat exchanger with corrugated louvered fins. The results have shown that flow depth, fin thickness and ratio of fin pitch and the number of the louvers are the main factors that influence significantly the thermal-hydraulic performance of the heat exchanger with corrugated louvered fins [6]. Kijung et al have reported about heat transfer and fluid flow correlations to describe the performance of heat exchangers that use corrugated louvered fins [7]. They have studied the parameters and optimization procedures to improve the performance of a corrugated louvered fin. In this work it has been found that the fin pitch, louver angle and louver pitch are the three important parameters which affect the performance of the corrugated fins [8]. Jang et al have analyzed the heat transfer and pressure drop characteristics of a primary surface heat exchanger (PSHE) with corrugated fins. Experimental results show that Nusselt number and friction factor correlations were suggested for a PSHE with corrugated surfaces [9].

Use of fins to increase convection heat transfer in an extensive engineering application; and increase the heat transfer rate from the surface area without increasing overall size of the application is a challenging issue. It is observed that heat transfer rate increases with perforations as compared to fins of similar dimensions without perforations. It is noted that in case of triangular perforations optimum higher heat transfer is achieved [10].

This paper gives a detailed comparative study on heat dissipation between a flat fin and a triangular corrugated fin. Both computational and experimental methods were applied to carry out the study.

2 Experimental

The general aim of this work is to analyze the effect of corrugated fins on heat transfer. The specific objectives are:

a. To study the effect of corrugated profile on heat transfer rate.

b. To design and develop a numerical model to analyze the corrugated fins.

c. To develop an experimental setup to study the effect of corrugated fins on heat transfer.

The simulation and experimental work has been carried out for flat and triangular corrugated fins. Design part of the fins was carried by Solid works 3D modelling software. Further, the 3D models were transferred to ANSYS meshing tool to generate the mesh. Heat transfer simulations were set up using FLUENT as solver. Along with the simulations, real fins were fabricated for the same dimensions. Then the fins were tested for heat dissipation using Heat Convection Trainer experimental machine.

2.1 Simulation Setup

The geometry of the fins was developed using Solidworks software. Each designed model contains three fins, with specific fin shape. As per the design, inside the same working domain, triangular corrugated fin has larger surface area than the flat fin. Air was let to flow over the fins from inlet to outlet of working boundary domain as shown in Figures 1 and 2. ANSYS-14 Meshing tool was used to generate the mesh and ANSYS-14 Fluent codes were used as CFD simulation tool. Figures 3 and 4 show the schematics of flat pins-3D and corrugated fins-3D, respectively.

Since accuracy of the simulation largely depends on the quality of mesh, care was taken while generating the mesh. Number of nodes for Flat fin were 40974 and for Triangular corrugated fins were 45180. The elements are 202065 for Flat fins and 225884 for Angular corrugated fins. Figures 5 and 6 illustrate the mesh for both flat and corrugated fins, respectively.

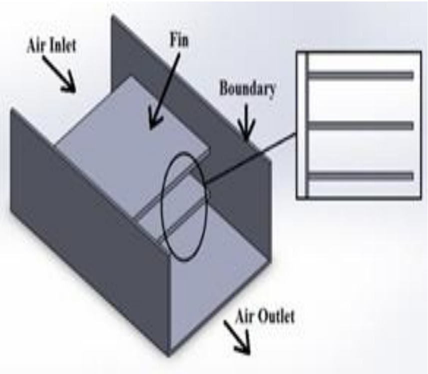

Figure 1: Schematic of Flat Fins-3D.

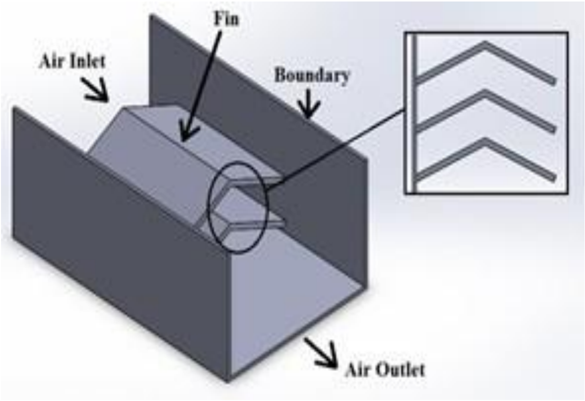

Figure 2: Schematic of Angular Corrugated Fins-3D.

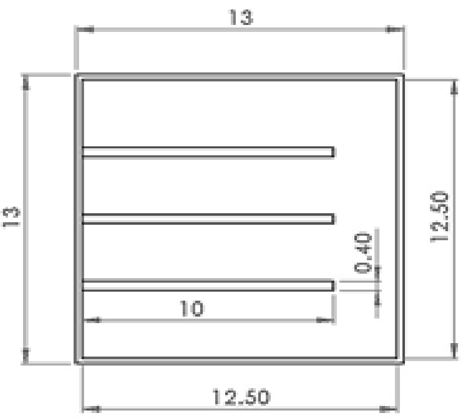

Figure 3: Schematic of Flat Fins-3D.

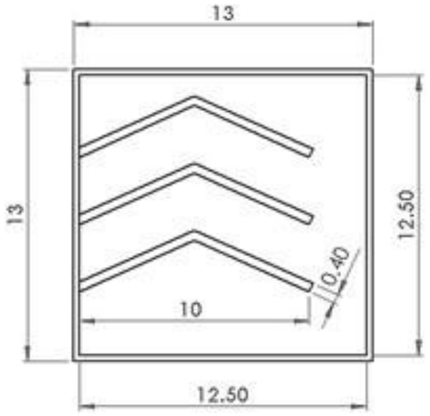

Figure 4: Schematic of Corrugated Fins-3D.

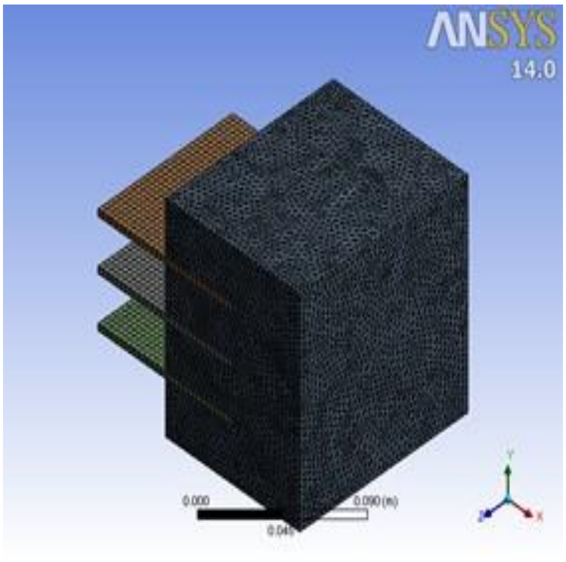

Figure 5: Mesh of Flat Fins.

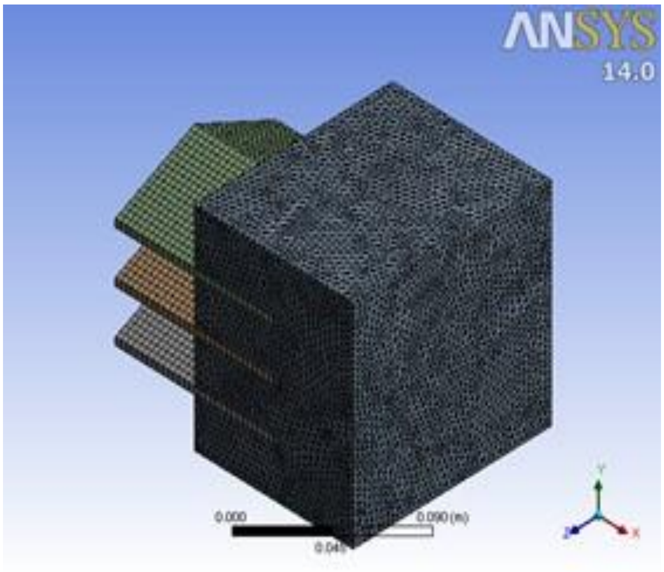

Figure 6: Mesh of Angular Corrugated Fins.

Laminar flow characteristics were setup in Fluent for each analysis conducted. Energy equations were ON to define heat transfer within the models setup. The material selected is Stainless Steel. The source term for heat enable and edit had the value of 1666750 W/m^3 for flat fin and 1540790.4 W/m^3 for triangular fin under zone conditions setup.

2.2 Experimental Setup

The main requirement for the experiment is to maintain a controlled atmosphere. Experimental setup was conducted in an air-conditioned lab. Figure 7 shows the experimental setup used in the current study; the parts of the equipment used are listed below. Figures 8 and 9 illustrate the fabricated flat fins and the corrugated fins respectively.

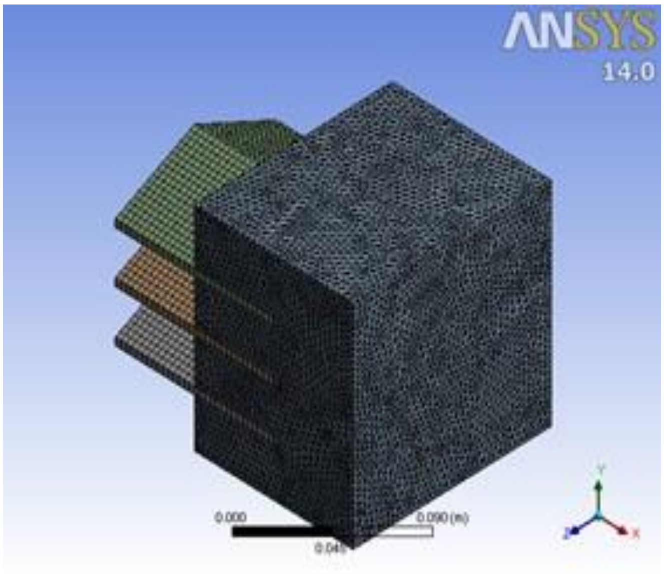

Figure 7: Experimental setup (Heat Convection Trainer-Model: TERA-CT-115.

1. Control Panel.
2. Heater Power Source Control.
3. Heat Power Source Socket.
4. Thermocouple-Air Outlet (2pcs).
5. Ducting-Exhaust Section.
6. Digital Thermometer.
7. Fin Outlet (1pc).
8. Interchangeable Heater Section.
9. Thermocouple-Fin Inlet (1pc).
10. Thermocouple-Air Inlet (2pcs).
11. Ducting-Intake Section.
12. Anemometer.
13. Thermocouple-Room (1pc).
14. Axial Fan.
15. Air Intake Control Valve.

Figure 8: Fabrication Design for Flat Fins.

Figure 9: Fabrication Design for Angular Fins under boundary conditions setup.

2.3 Experimental Procedures

Heat transfer experiments were conducted in following sequence:

First the Convection Heat Transfer Rig is connected to a 240 V AC single phase power source at then turn on the main switch from the control panel. Then ducting with heater box is inserted and observe the temperature without any heat generator is obtained. The temperature values are measured by the digital thermometer thermocouple sensors.

Switch on the fan and let the air run in the ducting for 5 minutes until the steady state condition is established and measure the air velocity by the anemometer prop where it is fitted into the ducting. The air velocity can be adjustable by the air inlet control valve.

Switch on the heater using the heater switch in control panel and then increase the heater power to 40% for 5 minutes, up to 60% for 5 minutes; at then increase it further to 90% for 20 minutes. During the given time period, record the first temperature data values for the air inlet and outlet as well as for the fin inlet and outlet temperatures, keep the heater at 90% for 5 minutes more to record the second data reading. Record the temperature values as well as the velocity in the data base sheet. It is not advisable to keep the heater at 100% to avoid any damage to the fins.

When the experiment is completed the heater is switched off first and the apparatus is allowed to cool for 5 or 10 minutes before the fan is switched off. The steps are repeated for several times with other heaters.

3 Results and Disussion

The results obtained from the simulation and experimental work carried out using the parameters defined above are shown below in Figures 10 and 11.

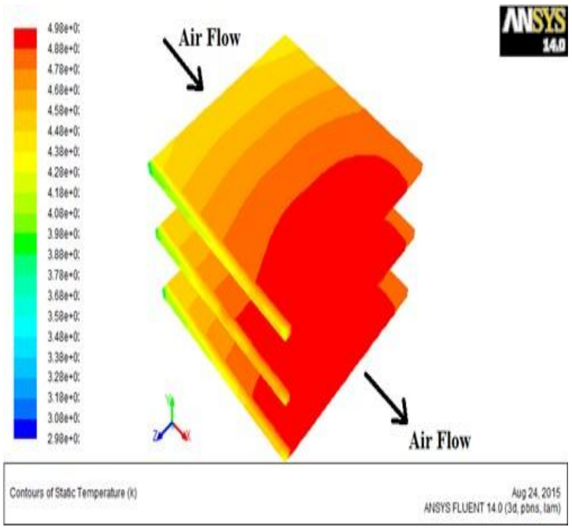

Figure 10: Static Temperature for Flat Fins.

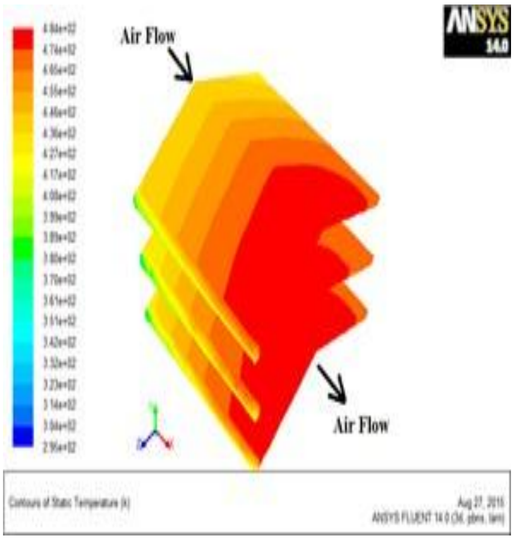

Figure 11: Static Temperature for Angular Corrugated Fins.

Table 1: Temperature comparison results from the simulation.

Design	Minimum Temperature (K)	Maximum Temperature (K)
Flat Fins	298	498
Angular Fins	295	484

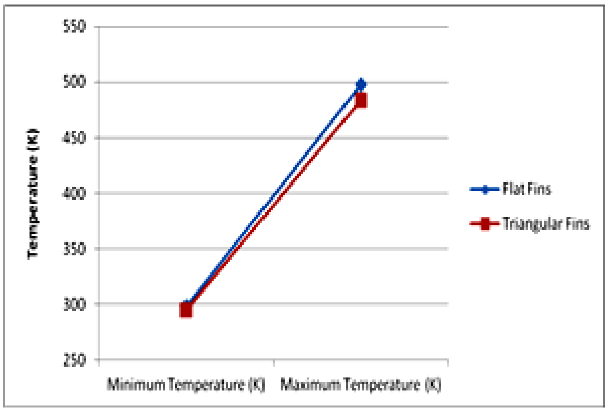

Figure 12: Temperature Comparison Results from the Simulation.

Table 2: Temperature comparison results from experiments.

Type	Minimum Temperature (K)	Maximum Temperature (K)
Flat	300.3	461.1
Angular	300.42	440.0

Based on the results obtained and as shown in figure 12, it has been observed that the angular shape with 484 K temperature is better than the flat shape with 498 K. The maximum temperature difference between both shapes was found to be 2.85%. Thus, it can be concluded that the angular fin with larger surface area has the higher cooling effect than the flat fin at constant velocity and temperature.

3.1 Experimental Results

Results were obtained from the experiments that were conducted several times in order to have stable data. The experimental results shown in Figure 13 illustrate that the maximum temperature for triangular fin was 461 K and for the flat fin was 440 K, with a temperature difference of 4.68%. It was found that the experimental results were similar in pattern with the simulation results as mentioned in table 1. The experimental results are tabulated in Table 2 which shows the temperature behavior for each type of the fins.

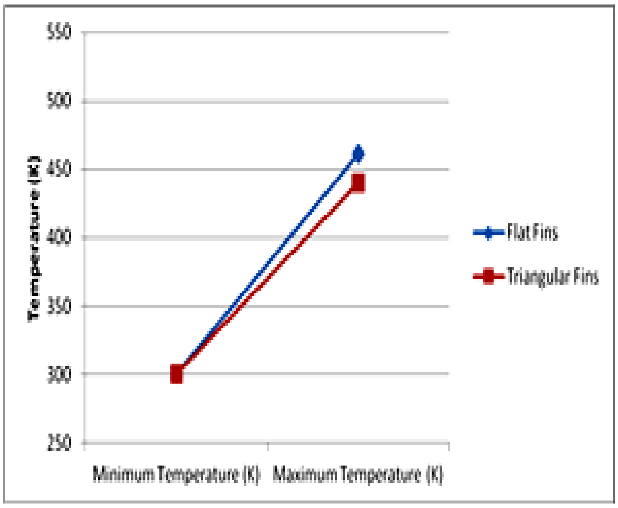

Figure 13: Temperature Comparison Results from Experiments.

3.2 Discussion

Based on the result obtained and as shown in figure 12, it is proven that the best fin shape with higher heat dissipation was achieved under corrugated fin than the flat fin. Therefore, the corrugation profiled fins with increased surface area could obtain the higher heat transfer rate compared to that of a flat fin. As experiments were conducted within the same boundary conditions and specified inlet velocity for various fin shapes, it has been proven that the heat dissipation has direct relation with corrugated fins.

4 Conclusion

In conclusion, CFD simulation and experimental work were carried out for the flat fin and corrugated fin to investigate the heat dissipation capacity. Enhanced heat dissipation was noted under corrugated fins due to increased surface area in comparison with flat fins. The effect of corrugated angular fins has been found to be 4.68% less than the flat fin in the temperature difference. Thus it can be concluded that the corrugated profiled fins have an improved heat dissipation and would be efficient in heat transfer applications.

References

[1]P. K. Kasana, "Computation of Heat Transfer Augmentation in a plate-fin heat Exchanger using Rectangular/Delta Wing", KURUKSHETRA-136119, India, 2010.

[2]Y. A. Cengel, "Heat and Mass Transfer: (SI Units): A Practical Approach", 3rd edition, 2006.

[3]G. Jogi Nikhil and M. Lawankar Shailendra, "Heat transfer analysis of corrugated plate heat exchanger of different plate geometry: A review", IJETAE, vol. 2, pp. 110-115, 2012.

[4] Tisekar Salman, A. Mukadam Shakeb, Vedapathak Harshad S, Rasal Priyanka K and Khandekar S.B, "Performance analysis of corrugated plate heat exchanger with water as working fluid", IJRET, vol. 5, pp. 56-62, 2016.

[5] Khoshvaght Aliabadi, Khoshvaght and Rahnama, "Thermal hydraulic characteristics of plate fin heat exchangers with corrugated/vortex-generator plate fin (CVGPF)", Applied Thermal Engineering, vol. 98, pp. 690-701, 2016.

[6] Zhao Gang Qi, Jiang Ping Chen and Zhi Jiu Chen, "Parametric study on the performance of a heat exchanger with corrugated louvered fins", Applied Thermal Engineering, Vol. 27, pp. 539-544, 2006.

[7] Kijung Ryu and Kwan Soo Lee, "Generalized heat transfer and fluid flow correlations for corrugated louvered fins", Int. J. of heat and mass transfer, Vol. 83, pp. 604-612, 2015.

[8] Kijung Ryu and Kwan Soo Lee, "Optimal design of a corrugated louvered fin", Applied thermal engineering, vol. 68, pp.76-79, 2014.

[9] Jang Won Seo, Chanyong Cho, Sangrae Lee and Young Don Choi, "Thermal characteristics of a primary surface heat exchanger with corrugated channels", Entropy, vol. 18, pp. 1-16, 2015.

[10]D. Kumbhar, N. K. Sane and C. S. T, "Finite Element Analysis and Experimental Study of Convective Heat Transfer Augmentation from Horizontal Rectangular Fin by Triangular Perforations," in Int. Conference on Advances in Mechanical Engineering, Gujarat, 2009.