

Numerical Investigation on Air Side Performance of Fin and Tube Heat Exchangers with Different Types of Fins

Pal Durgeshkumar K.¹, Sudhakar Umale²

¹M.Tech student, Mechanical Engineering

²Associate Professor in Mechanical Engineering
Sardar Patel College of Engineering
Mumbai-400058, Maharashtra, India.

Abstract— A 3-dimensional CFD model of two row finned tube heat exchanger with different fin patterns was investigated with FLUENT 14.5. Air side heat transfer and friction characteristics with three different types of fin having same global geometry have been investigated numerically. The fins were plain fin, slit fin and fin with vortex generator; they were numerically investigated with 5 different air flow ranging from 1 m/s to 3 m/s. the numerical results were compared with the experimental observations and high level of agreement were found between numerical and experimental results were found. Numerical results show that compared to slit fin, vortex generator fin have higher heat transfer performance. The vortex generator fin have lower pressure drop as compared to plain fin and slit fin.

Keywords- plain fin, slit fin, vortex generator, heat exchanger.

I. INTRODUCTION

A fin and tube heat exchanger is a piece of equipment built for efficient heat transfer from tube side to fin side. They are widely used in refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries.

Fins are used to increase the effective surface area of heat exchanger tubing. Finned tubes are used when the heat transfer coefficient on the outside of the tubes is appreciably lower than that on the inside. Various types of fins such as plain, wavy, slit, vortex generator, louvered, interrupted annular groove, etc. can be used to increase the effective heat transfer.[1]

Literature has been focused on data analysis, design analysis and to verify empirical correlations. Wang et al. [2] carried out experiments to test the dependence of heat transfer and pressure drop on the geometrical parameters of fifteen different tube-and-fin heat exchanger samples, fin spacing, fin thickness and number of tube rows which affect the Colburn j-factor and friction factor. The Colburn j-factor is the ratio of convection heat transfer (per unit duct surface area) to the amount virtually transferable (per unit of cross-sectional flow area) and Kayansayan [3] characterized that heat-transfer in tube-and-fin heat exchangers for

ten configurations for Reynolds numbers ranging from 100 to 30,000. These Reynolds numbers, with the Reynolds number characteristic dimension being the tube collar thickness, and studied in particular the effect of fins on heat transfer. Yan et al. [4] made a study to compare the plate, wavy, and louvered fin-and-tube heat transfer and pressure drop characteristics using different evaluation methods for the air side performance. Ay et al [5] conducted infrared thermographic experiments have been carried out to characterize the temperature distribution on the fins and calculate fin local convective heat transfer coefficients of staggered and in-line tube-and-fin heat exchanger arrangements. Mc. Quiston et al. [6,7] developed the correlations for both staggered and in-line heat exchangers to predict the friction factor and Colburn j-factors Fin spacing have stronger effect on slit fin patterns. Wang et. al [8] confirmed that both heat transfer coefficient and pressure drop decreased as fin spacing increased. As with other geometries there was a relatively small effect of number of tube rows on friction factor and decreased j factor for an increasing number of tube rows. In recent years, the implementation of vortex generators in fin-and-tube heat exchangers has received more and more attention. Fiebig [9] investigated numerically and experimentally embedded vortices in internal flow. Fiebig showed that longitudinal vortices have better heat transfer enhancement than transverse vortices for the same pressure loss. It was observed that winglets produces same heat transfer enhancement for less pressure loss as compared to wings. Deb et al. [10] analyzed numerically heat transfer characteristics and flow structure in laminar and turbulent flows through a rectangular channel containing built-in vortex generators by means of solutions of the Navier Stokes and energy equations. Jacobi and Shah [11] examined experimentally and numerically that flow structure and heat transfer effects of longitudinal vortices in a channel flow. Flow structure has been observed complex and consists of a main vortex, a corner vortex and induced vortex. The combined effect of these vortices distorted the temperature field in the channel and augmented heat transfer between the fluid and its neighbouring surfaces. It was numerically studied the

heat transfer characteristics and turbulent structure in a three dimensional turbulent boundary layer with longitudinal vortices. The disturbance of the boundary layer caused the best heat transfer enhancement in the region where the flows were directed toward the wall but the vortex core was the region of relatively lower mixing. Torii.et.al[12] conducted experimental study to obtain heat transfer and pressure loss in a fin-and-tube heat exchanger with inline or staggered tube banks with delta-winglet vortex generators of various configurations. The winglets were placed in a special orientation to augment heat transfer and reduce form drag. The change in Reynolds numbers ranging from 350 to 2100 has increased the heat transfer coefficient by 30-10% over the baseline case, and the corresponding pressure loss was reduced by 55-34%. Joardar and Jacobi [13] experimentally evaluated the potential of winglet-type vortex generator arrays for air-side heat transfer enhancement of a compact plain-fin-and-tube heat exchanger by full-scale wind-tunnel testing. They found that the air-side heat transfer coefficient increased from 16.5% to 44% for the single-row winglet arrangement with an increase in pressure drop of less than 12% and for the three-row vortex generator array the heat transfer coefficient increases from 29.9% to 68.8% with a pressure drop penalty from 26% to 87.5%. Mirzaei.et.al [14] numerically investigated the flow and heat transfer enhancement using an array of delta-winglet vortex generators in a fin-and-tube heat exchanger. They adopted “common-flow-up” arrangement for vortex generators in three different configurations. The 3VG-inline-array configuration achieves enhancements up to 32% in total heat flux and 74% in j-factor over the baseline case, with an associated pressure drop increase of about 41%.

II. OBJECTIVE

The objective of present study is to numerically investigate a 3-dimensional finned tube heat exchanger with different fin patterns having same global geometry. The study is focussed on comparing the simulation results of all the three heat exchangers and finding the best heat exchanger in the considered parameters.

I. PROBLEM DEFINITION

Various researchers have thoroughly studied the flow pattern over various types of heat exchangers; whereas these studies were mainly focused on effect of number of tube rows or fin spacing or longitudinal pitch or fin thickness on the heat transfer and friction characteristic of fin and tube heat exchanger; and that too limited to only one type of fin. various fins such as slit fin and vortex generator fin have remarkable effect on heat transfer and flow characteristics therefore, it is essential to investigate the heat transfer and friction characteristics of fin and tube heat exchangers with

same global geometry and different types of fin; and compare the result

In the present study air side heat transfer and friction performance of a two row fin and tube heat exchanger with three different fin patterns are investigated under 5 different air inlet velocities and compared.

II. NUMERICAL IMPLEMENTATION AND MATHEMATICAL MODELLING

A) Assumptions used for solver set up

At the upstream boundary conditions, the dry air entering the computational domain is assumed to have uniform velocity, temperature and laminar with the velocity components in the y and z directions considered to be zero. The fluid region comprises of the entrance, outlet & bundle zone and the solid region includes fin. At the solid surfaces no slip condition for the velocity are specified. Heat convection to the fin and heat conduction in the fin are considered. Constant temperature is assigned to the tube surface and all velocity components are set to be zero. At the symmetry planes, heat flux is assumed zero. The normal velocity component at the symmetry plane is zero, i.e. no convective flux across that symmetry plane occurs. Thus, the temperature gradients and tangential components of velocity gradients in normal direction are set to zero. The flow between fins is considered as laminar

B) Governing Equations.

The following Governing equations are considered[1]:

1. Mass conservation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

2. Momentum Conservation:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = g\beta(T - T_{ref}) + u \frac{\partial^2 v}{\partial x^2} + v \frac{\partial^2 v}{\partial y^2} + w \frac{\partial^2 v}{\partial z^2}$$

3 Energy Equation:

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\partial^2 T}{\partial z^2} \right)$$

C) Boundary conditions & material:

Fin and tube material : copper

Air inlet temperature : 300k

Tube inside temperature: 333k

Air inlet : velocity inlet with constant temperature.

Air outlet : pressure outlet

Tube inside: constant temperature wall.

Tube surfaces, Dirichlet BC:
 $T = T_w$, Air velocity: $u = v = w = 0$.
 Fins, Dirichlet BC:
 $T = T_{fw}$, Air velocity: $u = v = w = 0$
 Inlet, Dirichlet BC:
 Uniform velocity $u = u_{in}$, $v = w = 0$ $T = 300^{\circ}k$.
 Outlet, Neuman BC: Zero gradients, u , v , w ,
 pressure, and temperature. (One-way),
 Free stream planes: (top and bottom planes of the
 extended surface areas):
 $(\partial u/\partial z) = 0$, $(\partial v/\partial z) = 0$, $w = 0$, $(\partial T/\partial z) = 0$.
 Side planes:
 Symmetry planes: $(\partial u/\partial y) = 0$, $v = 0$, $(\partial w/\partial y) = 0$,
 $(\partial T/\partial y) = 0$.

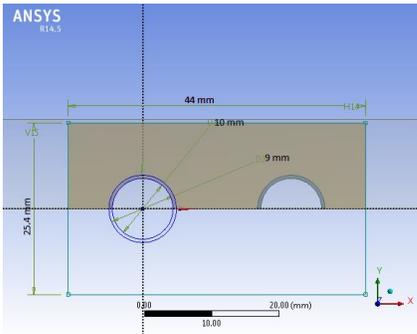


Fig1: schematic of plain fin

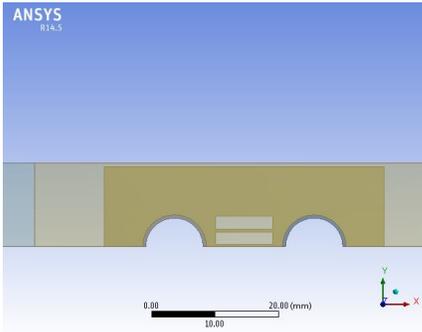


Fig2: schematic of slit fin

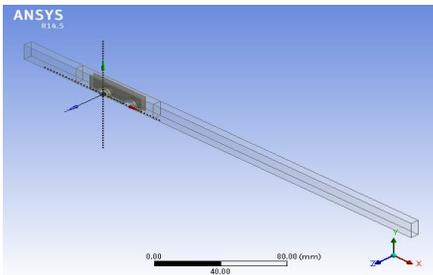


Fig3: Schematic of finned tube heat exchanger

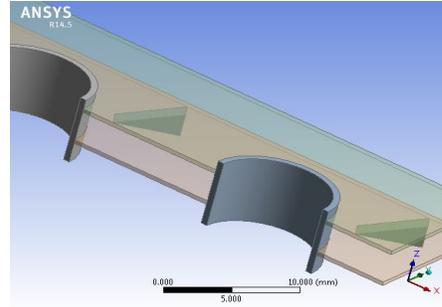


Fig4: schematic of vortex generator fin.

Geometric dimensions of fin tube heat exchanger:-

Internal diameter (Di): 9 mm
 Outer diameter (Do): 10 mm
 Fin thickness : 0.35 mm
 Fin collar outside diameter (Dc): 10.7 mm
 Fin pitch: 3 mm
 Transverse tube pitch: 25.4
 Longitudinal tube pitch: 22

Dimension of slit:-

Slit length: 9 mm
 Slit width: 1.5 mm
 Slit spacing: 1 mm

Dimensions of vortex generator:-

Length: 5 mm
 Thickness: 1.5 mm
 Height: 3 mm
 Angle of vorticity: 450
 Angle of attack: 450

Meshing was done in Ansys meshing by using patch independence scheme.

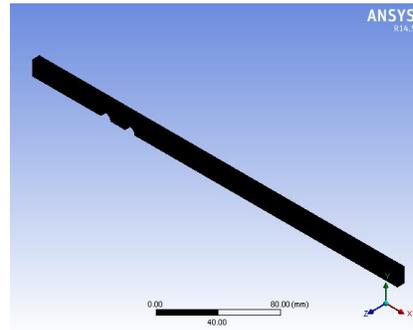


Fig5: Meshing of full model No. Of elements 22703

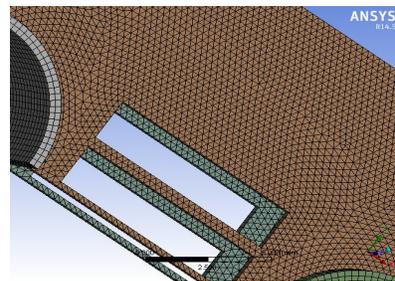


Fig6: slit fin mesh no.of elements 23873

Solution Methods:

- Scheme- SIMPLEX
 - Gradient- Least Square Cell Based
 - Pressure- Body Forced Weighted
 - Momentum and Energy-Second Order Upwind
- Solution Controls (under relaxation factors):
- Pressure-0.3
 - Density-1
 - Body force-1
 - Momentum-0.7

III. RESULTS AND DISCUSSION

The air side thermal performance of all heat exchangers was analysed. All three different types of heat exchangers were operated under same operating conditions. And their individual behavior have been analysed and their performances are compared afterwards.

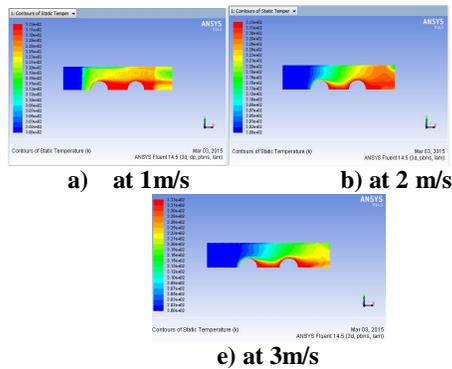


Fig.7: Temperature variation in plain fin at different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the plain finned heat exchanger at an interval of 0.5 m/s the air outlet temperature was measured and it is seen that as air velocity increases the air outlet temperature first increases and then decreases in the case of plain fin. The air outlet temperature was measured to be 318⁰K and 321⁰K at 3m/s and was seen 325⁰K at 2m/s.

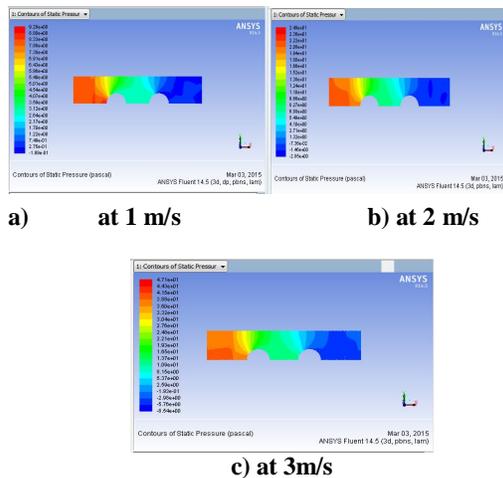


Fig.8: Pressure drop in plain fin at different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the plain finned heat exchanger at an interval of 0.5 m/s and the pressure drop was measured and it was seen that the pressure drop was increasing as the air inlet velocity was increased. At inlet velocity of 1m/s the pressure drop was seen to be 9 N/m² and at 3m/s it is 55.6 N/m²

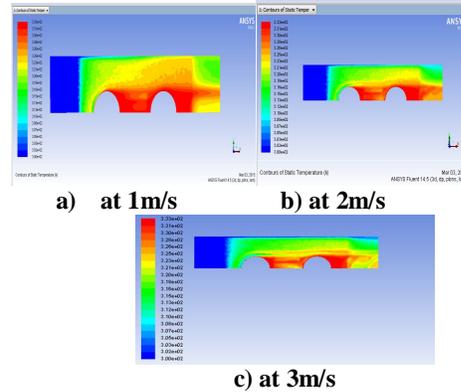


Fig.9: Temperature variation in slit fin at different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the slit finned heat exchanger at an interval of 0.5 m/s the air outlet temperature was measured and it is seen that as air velocity increases the air outlet temperature first increases and then decreases in the case of slit fin. The air outlet temperature was measured to be 318⁰K and 317⁰K at 3m/s and was seen 324⁰K at 2m/s.

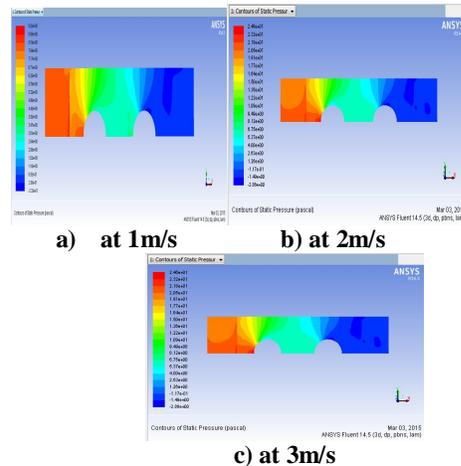


Fig.10: Pressure drop in plain fin at different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the slit finned heat exchanger at an interval of 0.5 m/s and the pressure drop was measured and it was seen that the pressure drop was increasing as the air inlet velocity was increased. At inlet velocity of 1m/s the pressure drop was seen to be 7 N/m² and at 3m/s it is 45 N/m²

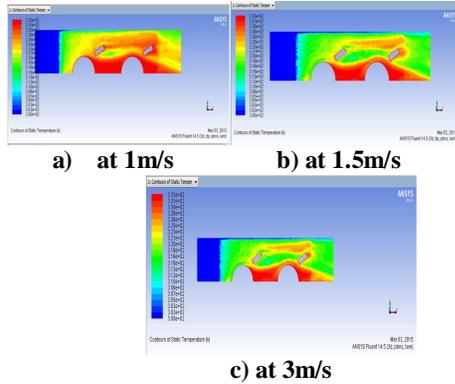


Fig.11: temperature variation in fin with vortex generator with different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the fin with vortex generator heat exchanger at an interval of 0.5 m/s the air outlet temperature was measured and it is seen that as air velocity increases the air outlet temperature first increases and then decreases in the case of vortex generator fin. The air outlet temperature was measured to be 325^oK and 316^oK at 3m/s and was seen 321^oK at 2m/s. a higher outlet temperature was seen when compared to other two; because vortex generator causes mixing of the air during the flow due to swirl produced by vortex generator hence the more time of contact with the fins and hence higher temperature. But at highest velocity of 3m/s the lowest temperature was seen may be due to the swirl produced at high velocity caused quicker escape from contact region hence lower outlet temperature.

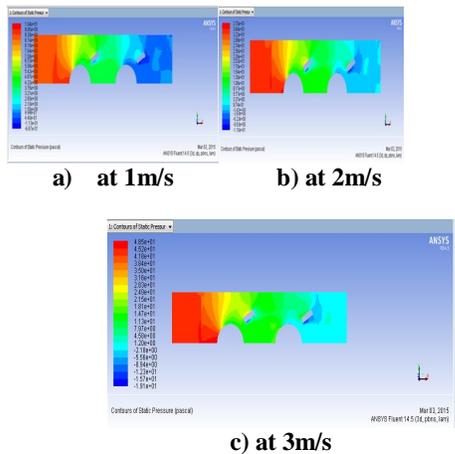


Fig.12: Pressure drop in fin with vortex generator different air velocities at inlet.

The air at the inlet velocity of 1m/s to 3m/s were passed through the fin with vortex generator heat exchanger at an interval of 0.5 m/s and the pressure drop was measured and it was seen that the pressure drop was increasing as the air inlet velocity was increased. At inlet velocity of 1m/s the pressure drop was seen to be 10.4 N/m² and at 3m/s it is 47.3 N/m²

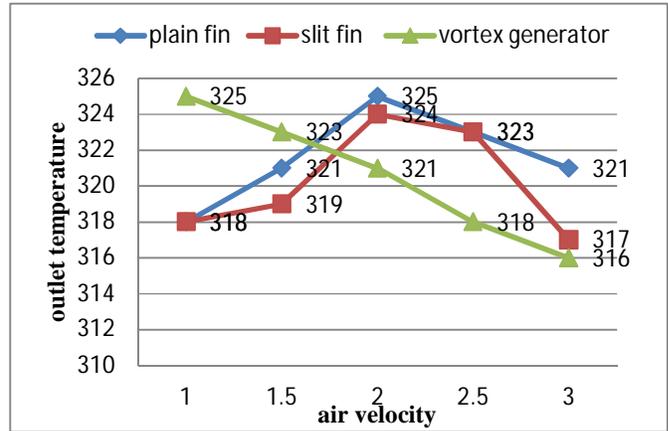


Fig.13: Outlet temperature variation with increase in air velocity

The air outlet temperature of all the three heat exchangers were compared and it was found that the vortex generator fin gives better heat transfer at lower inlet velocities, the air outlet temperature was compared at five different air velocities and it was found that the plain fin have shown higher heat transfer at higher velocities and the slit fin offers a comparatively lower heat transfer than fin. The vortex generator fin is showing a declining graph. Initially at lower air inlet velocity; the vortex generator enhances the heat transfer but as the air inlet velocity increases the air outlet temperature noticed was declining due to vortices generated of higher intensities and turbulent mixing causing less heat transfer time. And hence outlet temperature is decreasing with increase in air velocity.

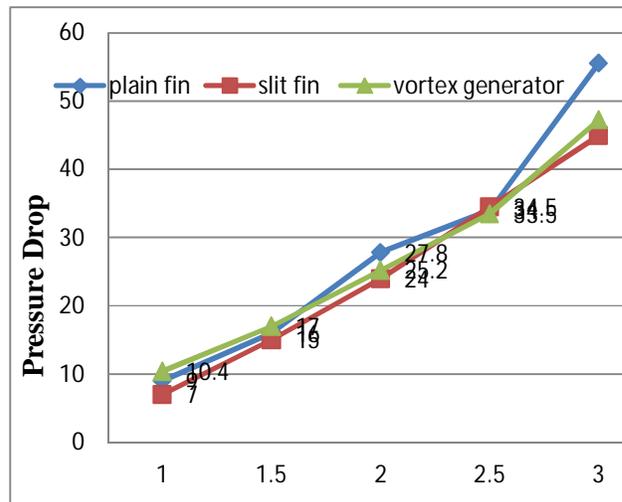


Fig.14: Effect of pressure drop on increase in air velocity.

The pressure drop of all the three heat exchanger were measured and it was found that Vortex generator fins provide lesser heat drop at higher air inlet velocity as

compared to the other heat exchanger; it have higher pressure drop at lower air inlet velocity i.e. 1 m/s it had higher value of 10.4 as compared to 7 for slit fin and 9 for plain fin.

The pressure drop in plain fin provides higher pressure drop and the slit fin seems to be having lower pressure drop.

It can be concluded that slit fin have better performance at all velocities.

IV. CONCLUSION

The air side heat transfer of three kinds of heat exchangers have been numerically investigated with ANSYS Fluent with air velocities 1, 2 and 3 m/s.

The main conclusion can be summarised as follows:-

1) Plain fin heat exchanger shows highest pressure drop when compared with other two heat exchangers. At air inlet velocity of 3m/s the plain fin heat exchanger gives highest pressured drop 55.6N/m^2 ; and the fin with vortex generator shows 14.92% lower drop and slit fin shows 19% lower drop.

2) At lower air inlet velocity fin with vortex generator shows higher air outlet temperature. i.e. at air inlet velocity of 1m/s shows 2.2% higher air outlet temperature 325K.

3) Vortex generator fin can give better heat transfer performance than slit fin.

4) Vortex generator fin gives lower heat transfer as compared to slit fin and plain fin at higher air inlet velocity

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