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Thermo-Hydraulic performance of internal finned annular tube heat exchangers

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Abstract: Numerical investigation conducted to determine wall temperature distribution along axial direction, outlet temperature, Nusselt number, convective heat transfer coefficient and friction factor for a turbulent flow through annular duct by solving conservation equations of mass, momentum, energy and turbulent equation using Fluent 14. A constant heat flux 3000w/m^2 was applied at the outer wall of the tube whereas the inner wall was considered as adiabatic. For the present study 1000 mm length aluminium pipe having an internal diameter 70 mm was considered. A comparison study between the plain tubes (without fins) with internal finned tube is also presented. Such comparison is to establish the influence of the presence of fins on heat transfer and pressure drop. From this investigation it was found that the fluid flow heat transfer characteristics of internal finned tube were better than the plain tube. It was also found that Nusselt number and pressure drop were increased with fin heights and fin numbers present in the annular space and Nusselt number were highest for trapezoidal shaped fins compared to other fin shapes.

Keywords: Numerical study, Annular duct, Friction factor, Pressure drop, Nusselt number, Turbulent heat transfer.

1. INTRODUCTION

Annulus internal finned tubes are widely used in many industrial as well as commercial applications starting from electronic industries to power generation industries for increasing the thermo-hydraulic behaviour. Conservation equations of mass, momentum and energy were solved numerically with 2-equations based *k-ε* model to determine the fluid flow and heat transfer behaviour of an internal finned annulus tube. The outer wall of the outer tube was subjected to constant and uniform heat flux of 3000 W/m^2 and the outer wall of the inner tube was considered as adiabatic.

Experimental study carried out by Yu et al. [1] to study the heat transfer and pressure drop characteristics of a double pipe heat exchanger with blocked and unblocked inner tube both friction and Nusselt number were correlated with Reynold's number. Nusselt number was function of Reynold's number found by Braga & Saboya [2] from experimental work with isothermal wall of inner tube and insulated outer wall having 20 numbers of fins. Heat transfer coefficients and friction factors were determined from the experimental work under turbulent flow condition through annular duct.

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with 560 internal fins where air was made to flow through the annular channel and water through the inner circular tube [3]. Kuvvet & Yavuj [4] performed experimental work on finned and unfinned tube concentric passages and concluded that Nusselt number for finned tube was 3.6 to 18 times compared to unfinned tube.

2. MATEMATICAL FORMULATIONS

The numerical study carried out for annulus tube of outer diameter, D_1, and inner surface diameter, D_2, and length, L as shown in the Fig. 1. Air enters into the annulus duct at one end and the other end is exposed to surrounding atmosphere.

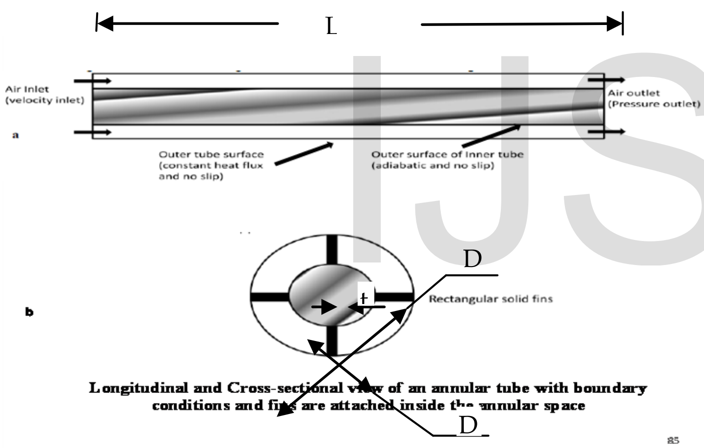

Figure 1

Fins are attached longitudinally and symmetrically within the space around inner periphery of the outer tube and rectangular fins are chosen for the initial study having length, L, thickness, t, and height H as shown in the Fig. 1. Subsequently the fin numbers, shapes and sizes have changed by keeping the mass flow rate inside the annular space constant. The flow field in the domain would be computed by using 3-D, incompressible Navier-stokes equations and 2-D axi-symmetric model for finless tube along with the energy equations. The working fluid used is air at temperature 300 K which is treated as incompressible and the inlet velocity is kept below 15 m/s. The outer wall of the outer tube is subjected to 3000 W/m^2 where as the outer wall of the inner tube is adiabatic. The outer wall is solid and has been given a no-slip and constant heat flux boundary condition where as the outer wall of the inner tube as adiabatic. Pressure outlet boundary condition has been imposed at the outlet of the tube whereas velocity inlet boundary condition employed at the inlet of the tube.

3. NUMERICAL SOLUTION PROCEDURES

3-D equations of mass, momentum, energy and turbulence have been solved by the algebraic multi-grid solver of Fluent 14 in an iterative manner by imposing proper boundary conditions. First order upwind scheme (for convective variables) was considered for momentum as well as for the turbulent discretized equations. As the density is taken as a function of temperature according to ideal gas equation therefore SIMPLE algorithm with PRESTO (pressure Staggered Option) scheme has been used for better convergence. Under relaxation factors (0.3 for pressure, 0.7 for momentum and 0.8 for k-ε) were used for the convergence of all the variables. Convergence of the discretized equations were said to have been achieved when all fields residuals for all variables fell below 10^{-3} and for energy equation residual was set to 10^{-6}.

4. RESULT AND DISCUSSIONS

4.1 Fin shapes

Figure 2 shows the wall temperature distribution for

different shape fins having same inlet mass flow rate

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of 0.0196 kg/s and fin height of 10 mm. For present numerical investigation 4 numbers of fins having different shape such as rectangular, trapezoidal, triangular and + (plus) shape fins are considered.

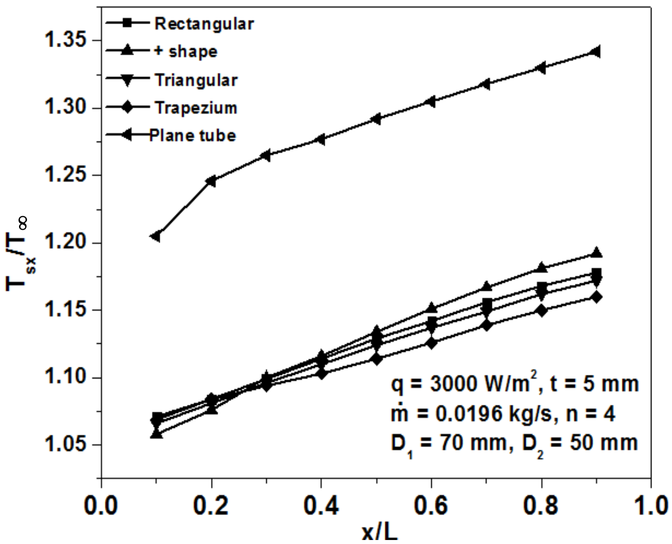

Figure 2

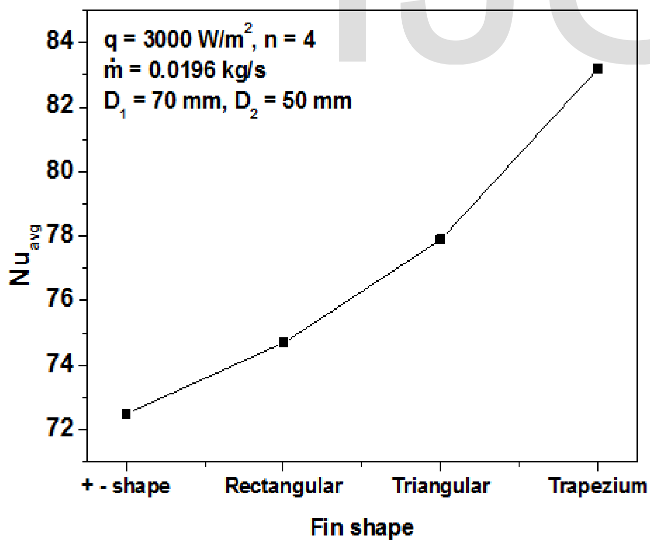

Figure 3

It can be seen from the plot that the wall temperature is minimum in trapezoidal shaped fin compared to other shapes that clearly indicates the heat transfer is highest for trapezoidal shaped fin due to better turbulent mixing. The same result is also visualised from Figure 3, where the Nusselt number for trapezoidal shaped fin is more compared to other.

4.2 Fin Height

Fin height plays a crucial role in transferring the heat in internal finned annular tube.

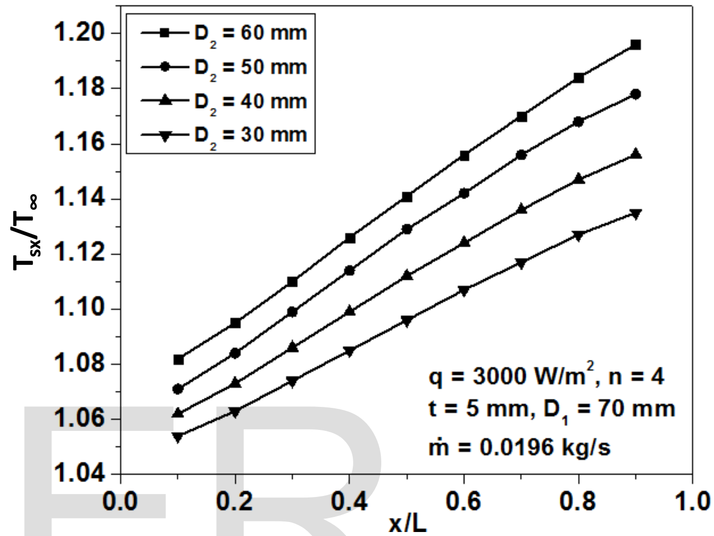

Figure 4

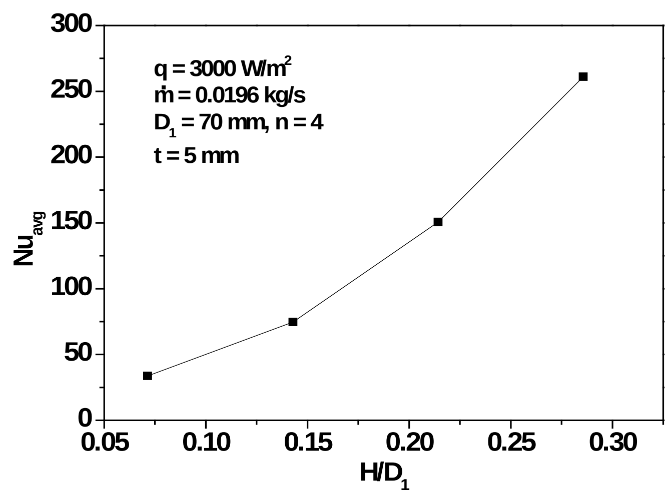

Figure 5

In the annular tube the outer tube diameter is kept constant with 70 mm where as inside tube diameter varies

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with fin height i.e. for a 70 mm outer tube diameter (D_1) and 30 mm inside diameter (D_2) the fin height (H) is 20 mm. The other operating parameter such as heat flux, mass flow rate of air and fin number are kept constant at 3000 W/m^2, 0.0196 kg/s and 4 respectively. It can be seen from the Figure 4, increasing the fin height or reducing the inner tube diameter, the wall temperature decreases where as average Nusselt number increases as seen from Figure 5. This clearly indicates that the heat transfer to air increases with fin height. But as the fin height increases the resistance to the air flow is more and due to that the pressure drop increases and the friction factor becoming more.

4.3 Fin Shape

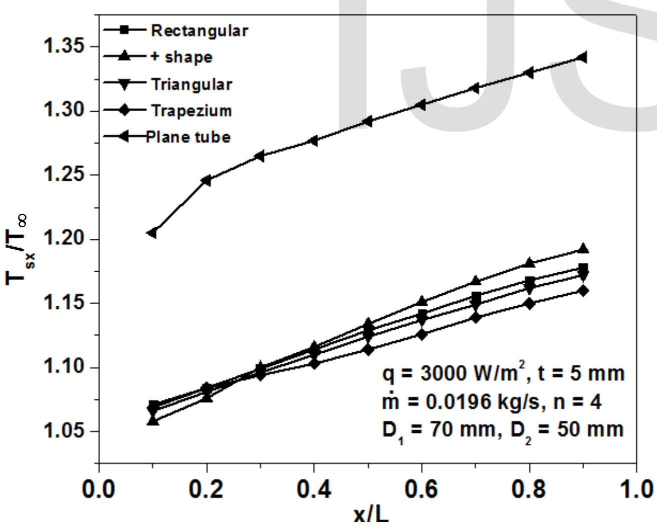

Figure 6

Figure 6, shows the wall temperature distribution for different shape fins having same inlet mass flow rate of 0.0196 kg/s and fin height of 10 mm. For present numerical investigation 4 numbers of fins having different shape such as rectangular, trapezoidal, triangular and + (plus) shape fins are considered. It can be seen from the plot that the wall temperature is minimum in trapezoidal shaped fin compared to other shapes that clearly indicates the heat transfer is highest for trapezoidal shaped fin due to better turbulent mixing. The same result is also visualised from Figure 7, where the Nusselt number for trapezoidal shaped fin is more compared to other.

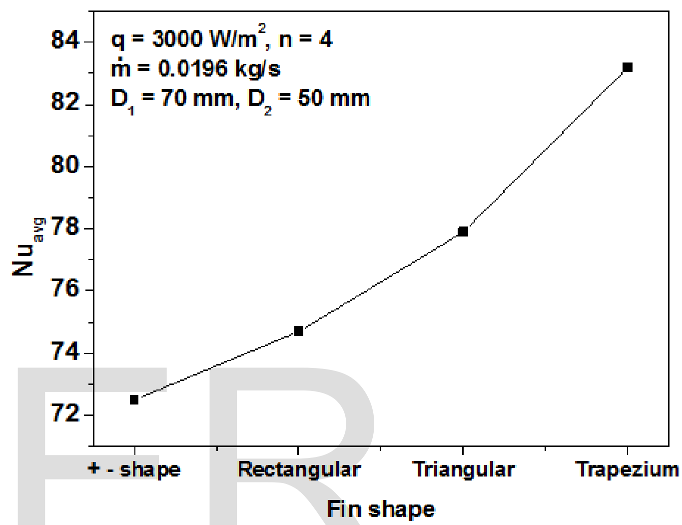

Figure 7

5. CONCLUSIONS

The wall temperature, tube outlet temperature and Nusselt number for finned annulus tube have been computed by solving the conservation equations for mass, momentum and energy with a two equation based k-ε turbulence model. The following conclusions can be drawn from the above numerical analysis:

- For an annulus finned tube by increasing the fin height and fin numbers the Nusselt number was found to be increased.
- It was also seen that the Nusselt number found to be highest in trapezoidal fin compared with other fin shapes.

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