HYDRODYNAMIC AND HEAT TRANSFER STUDY IN A CHANNEL WITH BAFFLE

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ABSTRACT

The research work has been conducted numerically to assess heat transfer and friction loss behaviors of steady incompressible turbulent flow of air through in a three-dimensional rectangular-channel in which baffles are arranged in staggered way on two opposite channel walls. The governing equations, namely, continuity, Navier–Stokes and energy, based on k–ε turbulence model to describe the turbulence phenomenon are solved using the finite volume method and the SIMPLE algorithm have been conducted for the fluid flow in terms of Reynolds numbers ranging from 20000 to 60000. Effects of different baffle heights and number of baffles on heat transfer and flow behaviors in the channel are examined Parameters varied are no of baffles and Reynolds number (Re). The axial velocity profiles, the velocity fields, the average coefficient of friction and the Nusselt number distribution were obtained for all the geometry considered. The results shows that the baffle provides the drastic increase in Nusselt number, friction factor values over the smooth wall channel due to better flow mixing from the formation of vortex flows generated by the baffle. In addition, substantial increases in Nusselt number and friction factor values are found for the rise in blockage ratio and/or for the increase in number of baffles.

Keywords: *Rectangular channel, hydrodynamic effect, friction factor, enhanced the heat transfer, turbulent flow.*

1. Introduction

Nowadays very limited amount of non conventional energy sources are available, hence the cost of the energy sources are very high. So we require using energy source efficiently. For decades, many engineering techniques have been developed for increasing the rate of convective heat transfer from the channel surface.Baffle plates play an important role in the dynamics of the flow through shell-and-tube heat exchangers air-cooled solar collectors, and internally cooled turbine blades. The reason of this may be that the use of rib/baffles completely makes the change of the flow field and thus the distribution of the local heat transfer coefficient. The rib/ baffles increase the degree of heat transfer coefficients and restart the boundary layer after flow reattachment between rib/baffles. Although heat transfer is increased through the rib/baffle arrangement, the pressure drop of the channel flow is also increase due to the decrease flow area effects. Therefore, the channel aspect ratio (AR), blockage ratio (b/B), Number of baffles and baffle arrangement are all parameters are important for both the heat transfer coefficient and the overall thermal performance. Techniques used for present work is passive techniques, because in active technique blower and vibration consume extra energy.

Recently, many investigations have been focused on the heat transfer in a channel with baffles.

Maximum number of research work has been done on the baffles arranged either parallel with the flow passage or perpendicular to it. The first work was conducted by Patankar et al.(1) investigated numerically of flow and heat transfer characteristics in a duct with the concept of periodically fully developed flow conditions. Tsay et al. (2) numerically investigated the heat transfer enhancement on a vertical baffle in backward facing step flow channel. the effect of the baffle height, thickness and the distance between the baffle and the backward facing step on the flow was studied. They found that an insertion of a baffle into the flow could increase the average Nusselt number by 190%. They also observed that the flow conditions and heat transfer characteristics are strong function of the baffle position. Bazdid-Tehrani and Naderi-Abadi (3) have been presented a numerical solution for the fluid flow and heat transfer in a duct with in line baffles and reported that the heat transfer behavior of this type of baffles is somewhat inefficient for large values of the blockage ratio. Mousavi and Hooman (4) investigated numerically of Laminar fluid flow and heat transfer in the entrance region of a two dimensional horizontal channel with isothermal walls and with staggered baffles. Data for heat and fluid flow as well as pressure drop are presented for Reynolds numbers ranging from 50 to 500 and baffle heights between 0 and 0.75. It has been observed that increasing the two parameters (blockage ratio and Reynolds number) will increase the Nusselt number, as expected. The results are reported for the thermal entrance region with 16 baffles. Prandtl number may vary from 0.35 to 10. Saim and Benzenine (5) investigated numerically of momentum and heat transfer characteristics with steady incompressible turbulent flow of air through channel. Reynolds number ranging between 12,000 and 38,000, the local and average coefficient of friction and the Nusselt number distribution were obtained for all the geometry considered and between the two inclined baffles and Suggest that the use of the inclined baffles induced with an improvement on the friction factor and the heat transfer intensity. Habib et al. (6) reported the characteristics of turbulent flow and heat transfer inside the periodic cell formed between segmented baffles staggered in a rectangular duct and pointed out that the pressure drop increases with the baffle height.

The present work is to study numerically of hydrodynamic as well as heat transfer study in a rectangular channel with baffles at turbulent fluid flow condition. Reynolds number vary from 20000-60000. Numerical study on blockage ratio and variation in number of baffles (n=3, 4) at same aspect ratio (B/L=0.5). Air is used as a working medium. Numerical result of friction factor and Nusselt number has been validated with Blasius and Dittus-Boelter correlations respectively.

2. Mathematical description

2.1 Numerical method

Three-dimensional turbulent force convection flow in a rectangular channel with baffles which is heated continuously at side wall is numerically simulated. The numerical simulations have been carried out using ANSYS-14.0 CFD Software package Fluent-6.3 version that uses the finite-volume method to solve the governing equations. Geometry has been created for air flowing in a one sided wall heated aluminum channel. Meshing has been created in ANSYS model with rectangular shapes. In this study Reynolds number varies between 20000 - 60000.

In this numerical simulation following boundary conditions are used as:

• The flow is three-dimensional and incompressible fluid flow.
• It is assumed that all external and baffle boundaries are stationary.
• The working medium is Air.
• The flow is assumed to be steady and turbulent.
• At the outlet, outlet pressure is equivalent to the atmospheric pressure.
• Body forces and viscous dissipation are ignored.

Based on the above assumptions, the following governing equations used to solve the incompressible, steady and turbulent fluid flow and heat transfer in the three dimensional computational channel are given as:

Continuity

$$\frac{\partial(\rho.u_i)}{\partial x_i} = 0 \quad (1)$$

Momentum

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \quad (2)$$

Energy equation

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_j}\left(\alpha \frac{\partial T}{\partial x_j}\right) \quad (3)$$

Where α is thermal diffusivity and is given by

$$\alpha = \frac{\upsilon}{Pr} \quad (4)$$

υ = kinematic viscosity

Inlet temperature of air is 300K and Prandtl number (Pr) is 0.75 for present numerical investigation. The physical properties of the air have been assumed to remain constant at mean temperature. The physical properties of the air have been assumed to remain constant at mean temperature. One side of channel wall is heated at 330K. Velocity inlet has been given for five different Reynolds number.

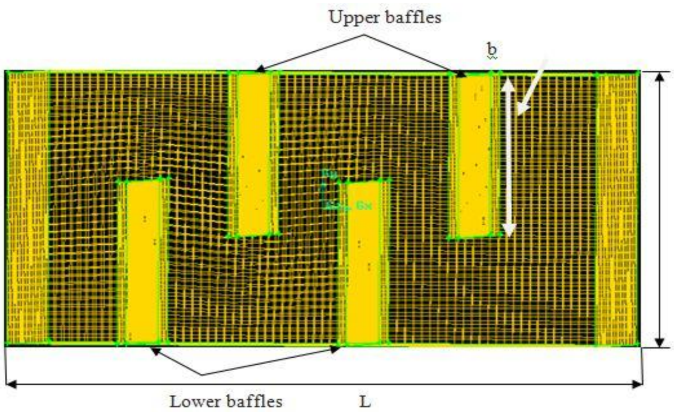

Fig -1 Channel geometry for computational study

The solutions were considered to be converged when the normalized residual values were less than 10^{-5} for all variables but less than 10^{-6} only for the energy equation. The first baffle is attached to the upper wall of the channel at distance of 6cm and the second inserted to the lower wall at 12.5cm from the entrance.

2.2 Non-dimensional parameter

Three parameters of interest in the present work are the Reynolds number, friction factor and Nusselt number. The Reynolds number is defined as

$$Re = \frac{\rho v D_h}{\mu} \quad (5)$$

The friction factor, f is computed by

$$f = \frac{2\tau_w}{\rho v^2} \quad (6)$$

τ_w = wall shear stress and value of τ_w has been given by fluent.

The heat transfer is measured by local Nusselt number which can be written as

$$Nu_x = \frac{h_x L}{k} \quad (7)$$

The average Nusselt number can be calculated by

$$Nu = \frac{1}{L}\int Nu_x \, \partial x \quad (8)$$

3. Grid Independency Test and Validation

3.1 Grid independence test

While changing the number grids a stage may come when the results are independent of the number of grids. These minimum number of grids after which there is no change in results were observed was known as optimum grid size and the results were independent of grids.

In the study, three different mesh sizes (80000, 125000 and 175000) are adopted in order to check the mesh independence. A detailed grid independence study has been performed, and results are obtained for the friction factor, wall shear stress, Nusselt number and pressure drop, but any considerable changes

was not obtained. Considerable percentage difference between the values of friction factor is less than ±5% for same Reynold number. In the test, the variation in friction factor for the 4 baffles at Re 15000 is marginal when increasing the number of cells beyond 175000, hence there is no such advantage in increasing the number of cells beyond this value. The results are shown in Table 1

The grid size of 175000 was chosen to model accurately the fluid flow in this problem and for further study.

Table 1:- Grid independency test for Reynolds Number 15000 and velocity = 1.095 m/s.

Parameter	Grid Size		
	80000	125000	175000
Friction Factor	0.02814	0.02848	0.02927
Wall shear stress	0.02066	0.02091	0.0215

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3.2 Validation of smooth channel

Verification of the heat transfer and friction factor of the smooth channel with no baffle is performed by comparing with the exact solutions as shown in Fig (2). The present numerical smooth Rectangular channel result is found to be in excellent agreement with exact solution values obtained from the open literature for both the Nusselt number and the friction factor, less than ±5% deviation. This provides a strong confidence in further investigation of the channel flow over the baffle.

The present numerical results on heat transfer and friction characteristics in a smooth wall channel are first validated in terms of Nusselt number and friction factor. The Nusselt number and friction factor obtained from the present smooth channel are, respectively, compared with the correlations of Dittus-Boelter and Blasius found in the open literature for turbulent flow in ducts.

Correlation of Dittus-Boelter,

$$\mathbf{Nu = 0.023}\ Re^{.8}\ Pr^{.4} \text{ for } Re \geq 10{,}000\text{, heating} \quad (9)$$

Correlation of Blasius,

$$f = 0.316Re^{-0.25} \text{ for } 3000 \leq Re < 20000 \quad (10)$$

Fig.(2) and (3) shows a comparison of friction factor and Nusselt number obtained from the present work with those from correlations. In the figures, the present results reasonably agree well within ±5% for both friction factor correlation of Blasius and Nusselt number correlation of Dittus-Boelter, respectively. The present Nusselt number and friction factor for the smooth channel are correlated as follows:

$$Nu = 0.049Re^{0.715}Pr^{0.4} \quad (11)$$

$$f = 0.344Re^{-0.259} \quad (12)$$

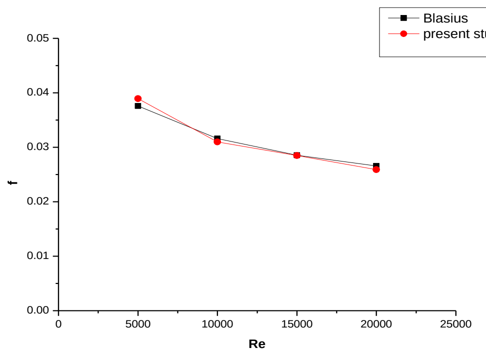


Fig. 2: Verification of friction factor for smooth channel.

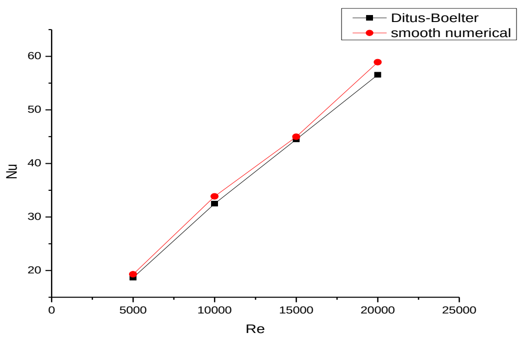


Fig .3: Verification of Nusselt number for smooth channel.

4. Results and Discussion

The study is focused on influence of vertical baffles on the dynamic and thermal behavior of the system for higher Reynolds number. Velocity profiles, friction factors, Nusselt numbers and isotherms are presented in two parts as hydrodynamics and heat transfer.

4.1 Hydrodynamics

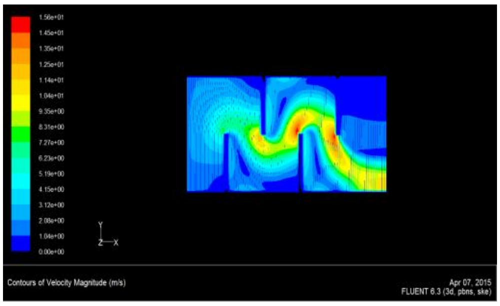
In this part we focus on pressure and velocity variation and effect on friction factor at same blockage ratio and variation in number of baffles.

The impact of the baffles on the flow structure of the near wall is presented in Fig.4(a–c) for 3 different parameters velocity variation Temperature variation and Dynamic pressure variation. As seen from the figure, a clockwise vortex is generated at the upstream region of the baffle. The dimensions of this vortexes are decreasing with increasing of

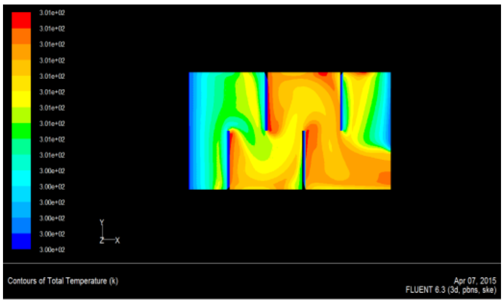
Reynolds number from Re = 20,000 to 60,000. Fluctuations between baffles and heated boundaries are increased with increasing of inlet fluid velocity.

In the upper part of the channel, velocities indicate the presence of the recirculation behind the first baffle. Its velocity is reduced in the upper part of the channel, while in the lower part is increased.

The effect of using the baffle on the isothermal pressure drop across the tested channel is presented in 4(c). The variation of the pressure drop is shown in terms of friction factor with Reynolds number. In the Fig5a, it is apparent that the use of baffle tabulators leads to a substantial increase in friction factor over the smooth channel.



(a)



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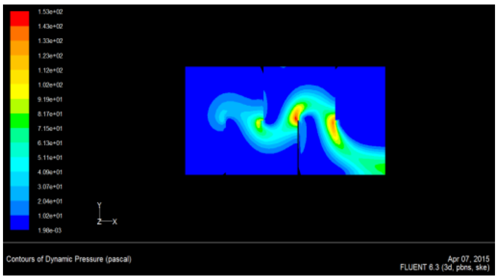
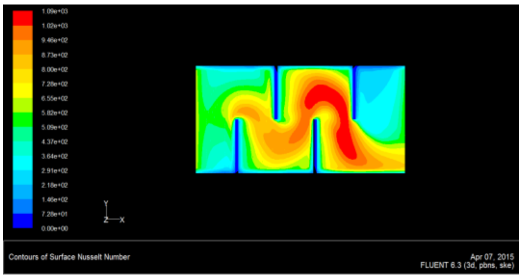


(c)

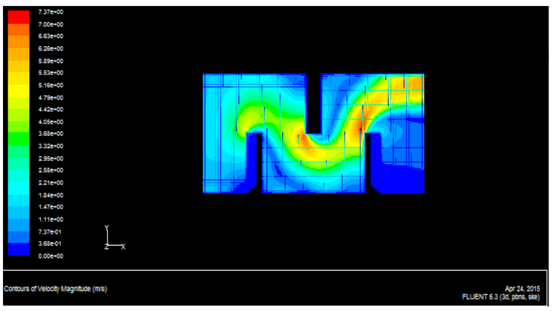


(d)

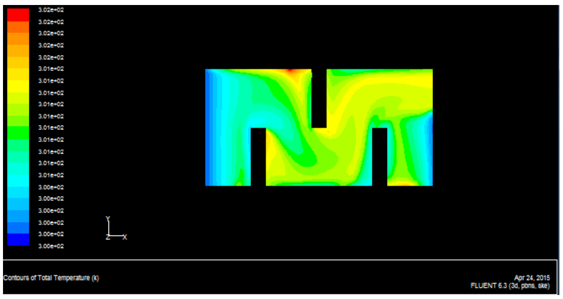
Fig 4 (a) Velocity, (b) Total Temperature, (c) Pressure,(d)Nusselt number profile for 4 baffles fitted in a channel with blockage ratio (b/B) =0.5 at velocity 1.37 m/s

4.2 Effect of Number of Baffles

The presence of the baffle in a channel affected the velocity field and also the pressure distribution in the whole domain, which is showing in the Fig. 4 (a-d). By placing of baffles is an important parameter to control heat transfer but the latter is concerned with the penalty in terms of friction coefficient, which leads to an increase in pressure drop. Effect of number of baffles has been shown in Fig 4 (a-d) and 5 (a-d) in which channel with 4 baffles generate more vortex comparison to channel with 3 baffles and causes more pressure drop and hence friction factor has been increases which has been show in Fig 6 (a). In channel with 4 baffles heat transfer has been increase compare to the channel with 3 baffles because of higher turbulent will be generated which has been shown in Fig 6 (b).



(a)



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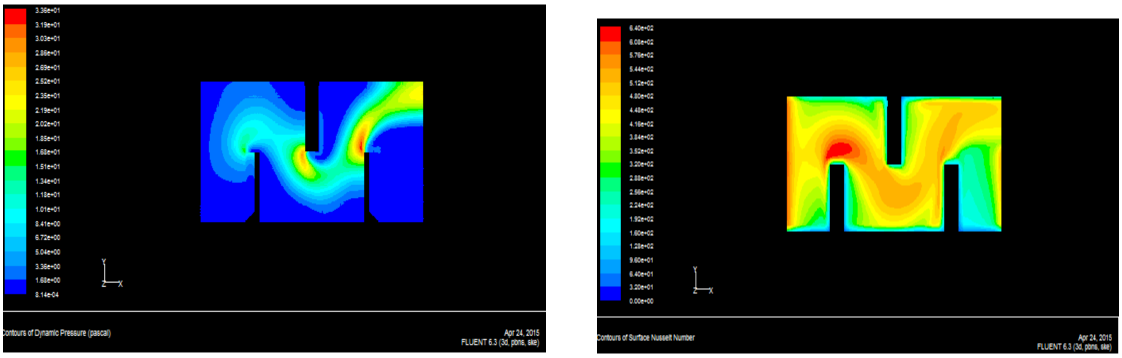

(c) (d)

Fig 5 (a) Velocity, (b) Total Temperature, (c) Pressure,(d)Nusselt number profile for 3 baffles fitted in a channel with blockage ratio (b/B) =0.5 at velocity 1.37 m/s

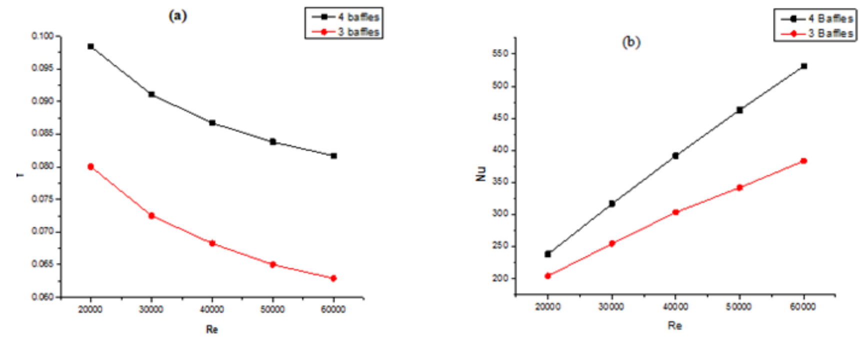

Fig.6. **Variation between (a) Re and f and (b) Re and Nu with number of baffles for BR=0.5.**

5. Conclusions

In general, Nusselt number increases whereas the friction factor decreases with an increase of Reynolds number. The values of Nusselt number and friction factor are substantially higher as compared to those obtained for smooth channel. This is due to distinct change in the fluid flow characteristics as a result of different baffle height that causes flow separations, and the generation of vortex flows. The major limitations of the present numerical study are that it is restricted to single value of Prandtl number such as Pr = 0.75. Numerical study has been carried out to investigate airflow friction and heat transfer characteristics in a low aspect ratio channel (AR=0.5) fitted with baffles in staggered way for the turbulent flow regime, Reynolds number of 20000 to 60,000. The Nusselt number augmentation tends to increase with the rise of Reynolds number in numerical result. The use of the more no of baffles causes a very high heat transfer and pressure drop increase as compared with less no of baffles used.

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