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3-D numerical study of the effect of Reynolds number and baffle angle on heat transfer and pressure drop of turbulent flow of air through rectangular duct of very small height[☆]

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Summary Present article illustrates a computational study of three-dimensional steady state heat transfer and high turbulent flow characteristics through a rectangular duct with constant heat fluxed upper wall and single rectangular cross-sectioned baffle insertion at different angles. RNG k—ε model along with standard wall function based computations has been accomplished applying the finite volume method, and SIMPLE algorithm has been executed for solving the governing equations. For a Reynolds number, *Re* of 10,000 to 50,000, Prandtl Number, Pr of 0.707 and baffle angle, α of 30°, 60°, 90°, 120°, 150°, computational studies are executed, centred onto the hydraulic diameter, D_h, test section and hydrodynamic entry length of the duct. Flow field has been solved using Ansys Fluent 14.0 software. Study exposes that baffled rectangular duct has a higher average Nusselt number, *Nu* and Darcy friction factor, *f* compared to a smooth rectangular duct. *Nu* as well as *f* are found to be maximum at 90° baffle angle. Results illustrate that both α and *Re* play a significant role in heat transfer as well as flow characteristics and also effects TEF. The correctness of the results attained in this study is corroborated by comparing the results with those existing in the literature for smooth rectangular duct within a precision of ±2% for *f* and ±4% for *Nu*.

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Introduction

The enhancement of heat transfer rate from any surface can be achieved by either increasing convective heat transfer coefficient or surface area of heat transfer applying the following extended surfaces onto the walls of the duct like ribs, baffles or fins.

Turbulent flow and heat transfer characteristics in rectangular ducts have been studied by a number of innovators. Tamna et al. (2014) examined heat transfer augmentation of turbulent flow of air in solar air heater fitted with multiple V-baffle. Turgut and Kizilirmak (2015) numerically studied steady state 3-D turbulent forced convection flow in a baffle inserted circular pipe. Tandiroglu (2006) examined the influence of flow geometry parameters on forced convection heat transfer in a transient state. Promvonge (Promvonge, 2010; Kwankaomeng and Promvonge, 2010; Promvonge et al., 2010) performed a computational study on turbulent forced convection heat transfer for airflow through a square duct at baffle angle 60°, 30° and 45° respectively.

In the present study, a rectangular duct of $D_h = 0.03636$ m with an inlet section of 1.65 m, test section of 0.65 m and exit section of 0.3 m (Tamna et al., 2014) is under prime focus under a boundary condition of velocity inlet and pressure outlet and constant heat flux of 600 W/m^2 on test section upper wall along with an assumption of constant working fluid properties of air at 300 K as well as mass flow rate in the flow direction. Conditions of no slip and impermeable boundary have been implemented over the duct as well as baffle wall. Hex-dominant meshing has been done for modelling the flow field and bearing in mind both solution accuracy and time convergent grid independency of 153,600 grids has been approved.

Validation of smooth duct

The present numerical results on heat transfer and head loss in a smooth duct are validated in terms of *Nu* with correlations of Dittus-Boelter, Colburn and *f* with Blasius, Petukhov correlations (Tamna et al., 2014) and (Turgut and Kizilirmak, 2015) for turbulent flow of air and shows brilliant covenant within +4.1% to −2%, −4% to 1.7%, +0.3% to −1.6% and 0.73% to −.75% respectively as shown in Fig. 1.

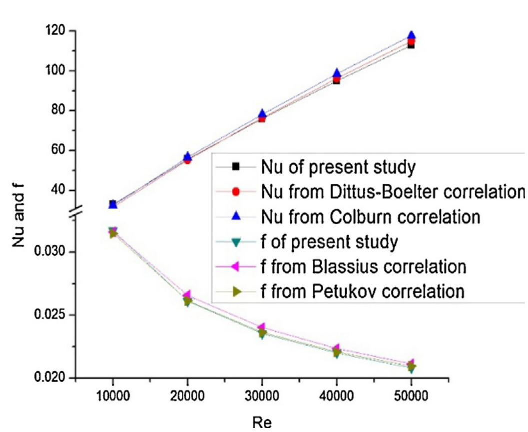

Figure 1 Comparison of *Nu* and *f* of present study with various correlations for smooth duct.

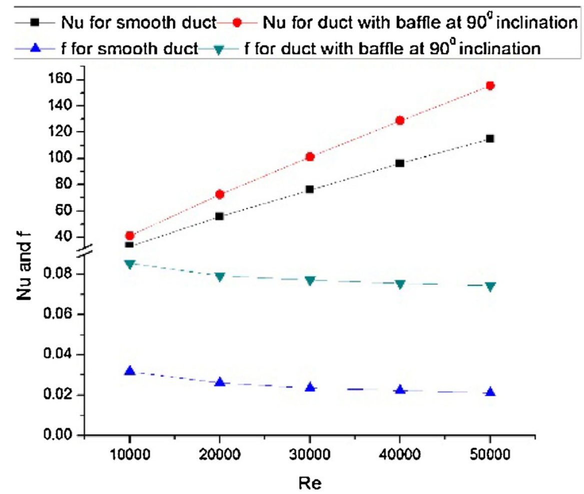

Figure 2 Variation of *Nu* and *f* with *Re* for 90° baffle inclination.

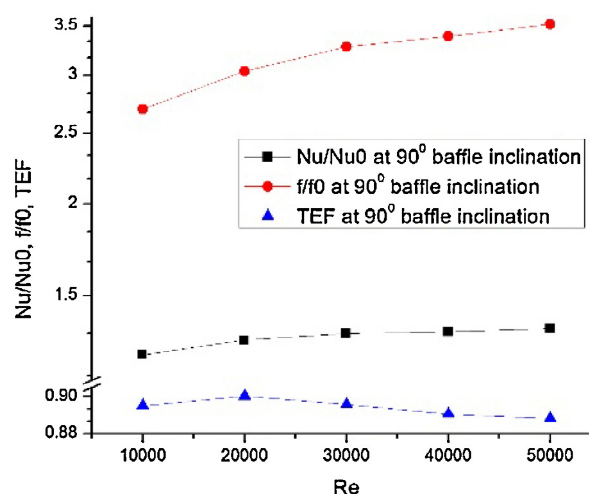

Figure 3 Variation of Nu/Nu_0, f/f_0 and TEF with *Re* for 90° baffle inclination.

Results and discussion

Effect of *Re* on *Nu*, *f* and TEF

A study of influence of *Re* onto the rate of heat transfer or heat carrying capacity of air flow defined by *Nu* and also the energy required for driving the same through the duct in terms of head loss or pressure drop along the duct defined by *f* is conceded out onto the present duct inserting a rectangular cross-sectioned baffle positioned at 1D_h downstream of the upper heat-fluxed wall of the test section. It has been revealed that *Nu* increases but *f* decrease with the increase of *Re* and also higher *Nu* and *f* then smooth duct due to the baffle insertion has been depicted clearly in Fig. 2 due to better thinning of thermal boundary layer on upper wall and flow separation respectively taking place behind the baffle.

Now f/f_0 ratio is more in contrast to Nu/Nu_0 and both upsurges with increasing *Re* (*Nu*, *f*, is for baffled duct and f_0, Nu_0 for smooth duct) portrayed clearly in Fig. 3 and

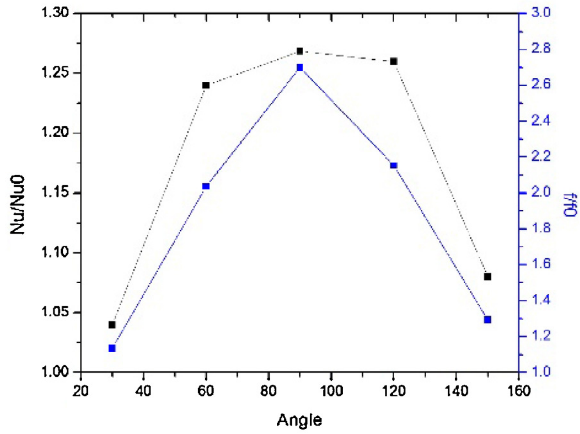

Figure 4 Variation of Nu/Nu_0 and f/f_0 with baffle inclination angle at *Re* 10,000.

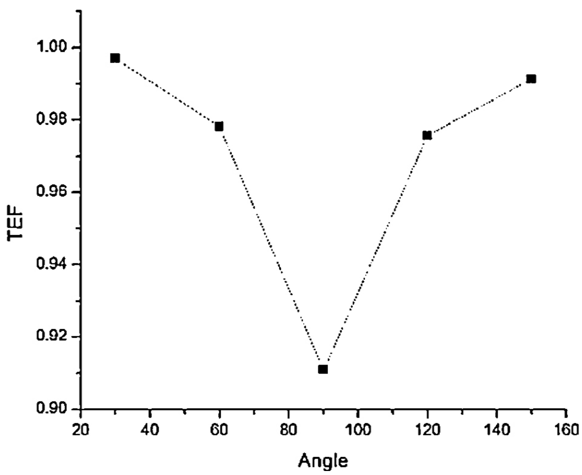

Figure 5 Variation of TEF with baffle inclination angle at *Re* 10,000.

TEF = $(Nu/Nu_0)/(f/f_0)^{1/3}$ slightly reduces with increasing *Re* for 90° baffle inclination as shown in Fig. 3.

Effect of α on *Nu*, *f* and TEF

It has been noticed that both Nu/Nu_0 and f/f_0 upsurges with increasing α from 30° to 90° and reduces with increasing α from 90° to 150°, *Nu* and *f* rises within 1.04 to 1.268 and 1.135 to 2.69 times than smooth duct respectively depicted clearly in Fig. 4. Maximum Nu/Nu_0 and f/f_0 have been detected at α of 90° because of better thinning of the upper heat fluxed wall's thermal boundary layer and higher total pressure drop respectively occurring just behind the baffle in this case compared to other angles. The respective baffle angle is taken with the direction of mean flow of air. Now the increment of *Nu* in contrast to the increment of *f* due to the baffle inclusion in comparison to smooth duct has been detected to be highest for α of 30° resulting maximum TEF and showing better performance during heat transfer of air flow through the duct at that baffle inclination as shown in Fig. 5.

Conclusion

For both smooth as well as baffled duct under study, *Nu* rises but *f* diminishes with growing *Re*. Due to the inclusion of baffle both *Nu* and *f* increases compared to the smooth duct with the highest increment of *Nu* by 35.12% at α of 90° and *Re* of 50,000 within the limit of constraints under study. It has been revealed that Nu/Nu_0, as well as f/f_0, rises with increasing *Re*. With the variation of baffle angle highest Nu/Nu_0 is obtained at α of 90° compared to other angles with a total increment of heat transfer rate by 24.56% at *Re* of 10,000 compared to the smooth duct. TEF slightly falls with rising *Re* at α of 90° and reduces with the alteration of α from 30° or 150° to 90° at *Re* of 10,000. Maximum TEF of 0.997 at 30° baffle inclination with *Re* of 10,000 and maximum *Nu* of 150.407 at 90° baffle inclination with *Re* of 50,000 has been exposed within the range of parameters under study. The performance of the present baffled duct can be amended by means of either fluid with higher Pr or other complex shaped vortex generators.

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