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Experimental study of heat transfer enhancement in square ducts with inserts

M.Udaya Kumar [1], Md.Yousuf Ali[2], M.Manzoor Hussian[3],

1.Research Scholar JNTUH, Hyderabad 2 .Professor Nawab Shah Alam Khan College of Engg and Tech , Hyderabad

3 .Professor JNTUH, Hyderabad

Abstract

This paper presents an experimental study of heat transfer and friction factor of plain square duct with inserts under turbulent flow condition constant heat flux. To conduct the experiments in plain square ducts, with and without inserts air is considered as the working fluid. In order to estimate the heat transfer coefficient and friction factor an experimental set up is fabricated. Experiments are first conducted in plain straight square duct with and without inserts and compared the data with existing literature values. The heat transfer characteristics are predicted under axially constant wall heat flux condition As such, the flow and heat transfer are periodically fully developed in axial direction turbulent heat convection in a square duct is one of the fundamental problem in a thermal science and Engineering. The enhancement of heat transfer in a duct is often achieved by forming some swirling or secondary flow is usually accompanied with high turbulent intensity, which promotes the mixing of different parts of fluids, hence enhances the heat transfer

1. Introduction

The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from issues such as long-term performance and the economic aspect of the equipment .The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power .In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Fluid flow and heat transfer in ducts occur in many engineering applications such as cooling in electric machineries, gas turbine blades, gaseous fuel supplies and other rotating systems. Heat transfer enhancement technology is the process of improving the performance of a heat transfer by increasing the convection and radiation heat transfer coefficients. Generally the main objective is to reduce the size and costs of these equipments. An increase in heat transfer coefficient generally leads to additional advantage of reducing temperature driving force, which increases second law efficiency and decreases entropy generation. Square ducts are widely used in heat transfer devices. For instance in compact heat exchangers, gas turbine cooling systems cooling chambers in combustion chambers and nuclear reactors. The experimental work of Mel ling and Whitelaw [1] shows detailed characteristics of turbulent flow in a rectangular duct where they used a laser-Doppler anemometer to report the axial development of the mean velocity, secondary mean velocity, etc. On the other hand, Hirota [2] present an experimental work on the turbulent heat transfer in a square duct; they show detailed characteristics of turbulent flow and temperature field. The forced turbulent heat convection in a square duct is one of the fundamental problems in the thermal science and fluid mechanics. Several experimental and numerical studies have been conducted on turbulent flow though a non-circular duct, specifically, (Nikuradse[3]; Gessner and Emery [4]; Gessner and Po [5]; Nakayama [6]; Myon and Kobayashi [7]; Assato [8]; In forced –convection heat transfer for turbulent flow in a square duct , thermal energy is also transported by secondary flow of the second kind.Therefore it is expected that the characteristics of the temperature field as well as flow field become more complex than those in a circular pipe and 2-D channel. In general turbulent heat transfer in the duct is dominated by the transport of heat by turbulence. The aim of this work is to supply information, gained on the basis of measurements and numerical calculations, concerning the flow of the fluid in the wide range of Reynolds number, in the area of ducts with different inserts. In recent years, the EGM method has been widely utilized in order to evaluate the relative merits of various augmentation techniques. This method has also been used by Lin and Lee [9] for optimization of pin-fin array under cross flow and by Zimparov [10] in order to study the effectiveness of different inserts in tubes. it is obvious that the EGM method combined with the first law analysis provides the most powerful tool for the analysis of thermal-hydraulic performance of any augmentation technique. As far as ducts of non-circular cross sections are concerned, Sekuli_c [11] and S¸ ahin [12] have presented analyses of irreversibility's associated with ducts of various shapes (namely, circular, square, equilaterally triangular, rectangular and sinusoidal) for laminar flow conditions,Heat Transfer Behaviour in a Square Duct with Tandem Wire Coil Element Insert The full-length wire coil provides higher heat transfer and friction factor than the tandem wire coil elements under the same operating conditions. Chang [13] investigated the heat transfer and pressure drop characteristics in tube fitted with serrated twisted tape. In their work, the serrations on two edges of the twisted tape with twist ratios of 1.56, 1.88, 2.81 and ∞ were the square-sectioned ribs with the identical rib pitch and height. Saha. [14] Conducted the heat transfer and pressure drop characteristics of laminar flow in a tube fitted with regularly spaced twisted-tape elements. Effects of the Reynolds number, Prandtl number, twist ratio, space ratio, and rod-to tube diameter ratio on heat transfer rate were also reported. Eiamsaard [15] studied the heat transfer and friction factor in a tube fitted with regularly spaced twisted tape elements. Effects of the (1) full length typical twisted tape at different twisted ratios, and (2) twisted tape with various free space ratios (S=1.0, 2.0, and 3.0) were reported. CineUK Thianpong, Petpices Eiamisa-ard, Khwanchit Wong charee Smith Eiamsa –ard [16] Compound heat transfer enhancement of a dimpled tube with a twisted tape swirl generator..The experimental results reveal that both heat transfer coefficient and friction factor in the dimpled tube fitted with the twisted tape , higher than those in the dimple tube acting alone and plain tube. . Khan Rezaul karim , Md. Morad Hossian Mollah, M.A.T. Ali, M.A. R.Akhananda, and Md.A .R. Sarkar:[17] This paper deals with The turbulent flow characteristics obtained in forced convection heat transfer with asymmetric heating has been carried in developed region of square duct. The experiments have been conducted for different Reynolds number varies from 50000 to 560000.It is found in the result that Nusselt number increases by 25.75percent varies in saw tooth backward, 27.43 percent in saw tooth forward,26.71 percent in triangular 24.43percent in trapezoidal ribbed wall over non ribbed wall with an increase of Reynolds number up to 12 percent. Tariq A. Al-Azab, Abdullah H. Al-Essa Effect of Rectangular perforation aspect ratio on fin performance It is found that the heat dissipation from the fin with rectangular perforation of aspect ratio of one (square perforation) is more than that of fin with other rectangular perforations.

2.Nomenclature

A convective heat transfer area (πDL), (m²)
Aarea of orifice, (m²)
C_p specific heat of air, (J/kg K)
d air discharge through test section (m³/sec)
D_h hydraulic diameter ($4A/P$), (m)

D Inner diameter of test section, (m)
f_{the} friction factor(theoretical) for plain square duct
f friction factor(experimental) for plain square duct
fi friction factor obtained using inserts
h experimental convective heat transfer coefficient, (W/m²K)
h_m manometer level difference,(m)
h_{air} equivalent height of air column, (m)
k thermal conductivity, (W/mK)
L length of test section, (m)
m**.** mass flow rate of air, (Kg/sec)
N_{ui} Nusselt number (experimental) with inserts, (hDh/k)
N_u Nusselt number (experimental) for plain square duct
N_{uthe} Nusselt number for plain square duct(theoretical)
P_r Prandtl number
P wetted perimeter, (m)
ΔP pressure drop across the test section, (Pa)
R_e Reynolds number, ($\rho\, u\, D/\mu$)
$T1$, $T10$ - air temperature at inlet and outlet, (°C)
$T2$, $T3$, $T4$, $T5$, T6, T7, T8, T9, - duct wall temperatures, (°C)
T_s average Surface temperature of the working fluid, (°C)
T_b bulk temperature, (°C)
T_e means temperature, (°C)
V velocity of flow (m/sec)
U air velocity through test section, (m/sec)
Greek symbols
ν Kinematic viscosity of air, (m²/sec)
μ dynamic viscosity, (kg/m s)
η Over all enhancement ratio
ρ_a density of air (Kg/m³)
v *velocity* (m/sec)
Nu Nusselt number
d_i inside diameter of the duct (m)
d_o outside diameter of the duct(m)
Q Total heat input W
q Heat flux (W/m^2)
L length of the duct(m)

H Height of insert, (m)
D_e Equivalent diameter (m)
$(4A_c/p)$

3. IMPORTANT DEFINITIONS

In this section a few important terms commonly used in heat transfer Augmentation work is defined.

3.1 Thermo hydraulic performance

For a particular Reynolds number, the thermo hydraulic performance of an insert is said to be good if the heat transfer coefficient increases significantly with a minimum increase in friction factor. Thermo hydraulic performance estimation is generally used to compare the performance of different inserts such as twisted tape, wire coil, etc., under a particular fluid flow condition.

3.2 Overall enhancement ratio

The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio .This parameter is also used to compare different passive techniques and enables a comparison of two different methods for the same pressure drop. The friction factor is a measure of head loss or pumping power.

3.3 Nusselt number

The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.

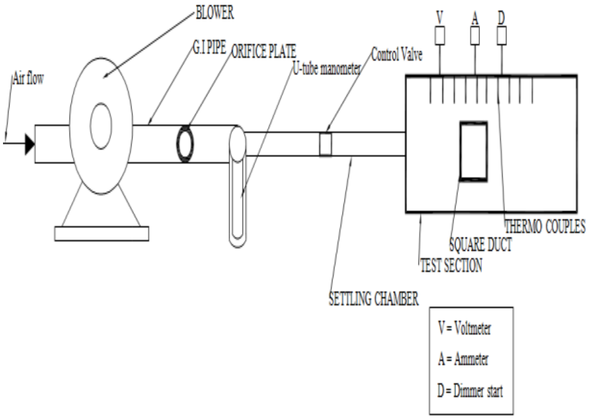
3.4 Prandtl number

The Prandtl number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat.

3.5. Aspect ratio

It is ratio of duct width to duct height. This factor also plays very crucial role in investigating thermo-hydraulic performance.

The experimental setup consists of 1.5 KW blowers, air at a room temperature flows into test duct through a orifice flow meter and a settling chamber. an orifice plate to measure the volume flow rate, water was used in U-tube manometer to ensure reasonably accurate measurement of the pressure .Temperature indicators provided to record the temperature of inlet and outlet test section The test duct has square cross section of 70x70 mm length of 3000 mm The walls of the test duct are hydraulically smooth. Square duct is made of Aluminium all walls of inner duct and Aluminium are heated isothermally at a appropriate temperature by the hot air is supplied between test section and square duct. In order to maintain isothermal heating condition and with high accuracy , wall temperature distributions were measured over the heated part with 10 thermocouples with .1 degree resolution. Control valve is connected to regulate or control flow it is coupled with settling chamber. The outer surface of the test tube was well insulated to minimize convective heat loss to surroundings, and necessary precautions were taken to prevent leakages from the system. In the present work hot air is entered into the G.I.pipe(30 cm length, 42mm ID) after that it is passing through orifice flow meter which is connected with U-Tube manometer again it is coupled with G.I.pipe (15 cm length, 34mm ID) then it is connected with settling chamber of 500mm length. Finally it is attached to a test section of length 3000mm .Inside the test section square duct is inserted and observes temperature readings, mass flow rate, and volume flow rate under constant heat flux condition and calculate Reynolds number, Nusselt number, friction factor, heat transfer coefficient. In the experiments, it was necessary to record the data of temperature, volumetric flow rate and pressure drop of the air at steady state conditions in which the inlet air temperature were maintained at 25 degree centigrade .The Reynolds number of the air was varied between 15000 and 25000.The local wall temperature (T_w) , inlet and outlet air temperature , the pressure drop across the test section and airflow velocity were measured for heat transfer of the heated duct with inserts. In this work we found the heat transfer rate and friction factor characteristics of uniform heat flux tube fitted with square duct. The Nusselt number of various ducts inserts increases when compared with those from the plain square duct. In the fig1 inserts yield a considerable heat transfer enhancement with similar trend in comparison with the plain square duct, and the Nusselt number from inserts increases for rising Reynolds number. This is because the inserts interrupt the development of the boundary layer of the fluid flow and increase the degree of turbulence. The fig no2 shows that Reynolds number increases with increase of Nusselt number The enhancement efficiency tends to increase with the increase of Reynolds number. There is a small increase in the enhancement of efficiency with the increase of Reynolds number.



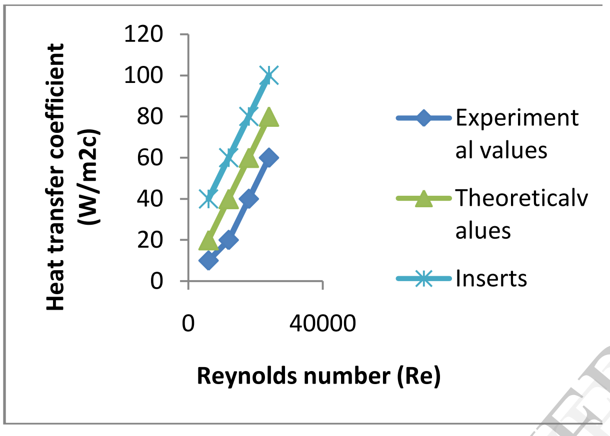


Fig1

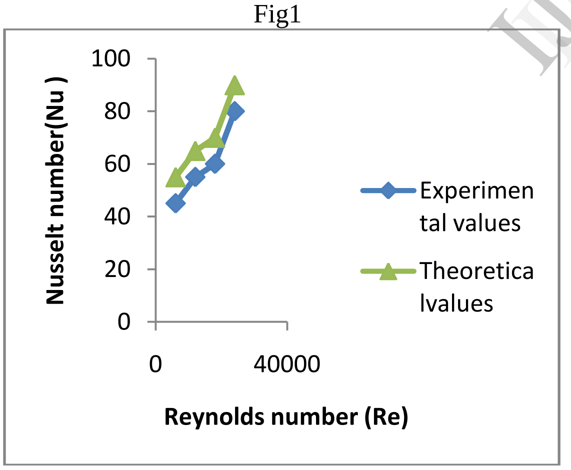


Fig: 2

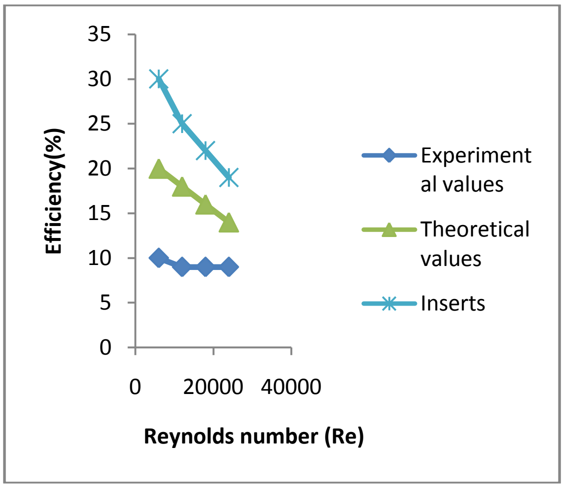


Fig: 3

5. Heat Transfer calculations

$T_s = (T2+T3+T4+T5+T6+T7+T8+T9)/8$
, $T_b = (T1+T10)/2$
Mean temperature, $T_e = (T_s+T_b) / 2$
Reynolds Number,
$D_e = 4A_c /p$
Nusselt Number:
Experimental Nusselt Number (Nu):
Heat transfer coefficient, h = q/(Ts-Tb)
Heat flux, q =Q/A
(2)**Theoretical Nusselt Number (Nu_{the}):**
Sider and Tate:
$Nu_{theo} = 0.036 * Re^{0.8} * Pr^{0.33} * (d_i / L)^{0.05}$
$Q = m* C_p *(T1-T10)$
$f_{the} = 0.25 (1.82 * \log10 R_e D -1.64)-2$
$f = \Delta P / ((L/D) (\rho a U^2/2))$
$\eta = (N_{ui}/N_u)/ (f_i/f)0.\ 333$

In this study, the experimental results of the duct fitted with short length of different inserts that effect on the heat transfer rate, friction factor, enhancement efficiency behaviours are investigated. The result of the heat transfer and friction factor from the plain square duct are confirmed with previous correlations [13],for example, Diitus-Boelter equation or Giellinski equation for heat transfer and Petukhov equation or Blasius equation for friction factor as depicted in the Figs, 3 and 4, respectively .

6. Results

The experimental heat transfer of the plain square duct fitted with inserts measured under heat flux condition The full length square duct is used as a continuous swirling flow over the test duct length for (a) increasing the residence time flow (b) Nusselt number increases with the rise of Reynolds number for inserts. The friction factor of the square duct with/without inserts for different lengths are calculated .The experimental set up is first tested with air as the working medium .From the experimental analysis it is observed that heat transfer coefficient increases by inserting the inserts, because it will act as a an obstruction to the flow of the air and hence heat transfer rate increases.

7. Conclusions

Influence of the square duct with different inserts on the heat transfer Nusselt number, Reynolds number, friction factor characteristics have been investigated experimentally. In this research The comparisons between the Nusselt number against Reynolds number are made among the experimental result .It is seen that for an increase Reynolds number up to 15%;Nusselt number increased by 30% It is observed that experimental heat transfer coefficient of air increases by inserting the different inserts Finally by doing this experiment we found how ducts are to be used more effectively and also the inserts are to be influenced to increase heat transfer coefficient, Reynolds number, Nusselt number which in turns to influence reduce the expensive cost of equipment and losses also. An experimental study has been performed to investigate the air flow and friction and heat transfer characteristics in a plain square duct fitted with inserts for the turbulent regime. Re 5000-25000. We observed that the heat transfer in case of inserts is highest as compare to the plain square duct.

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