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Experimental Study on Heat Transfer in Square Duct with Elliptical Rib Inserts

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Abstract -- This paper presents an experimental investigation on the thermal and friction characteristics of a square duct with inserts. The duct has a square section and uniform heat flux walls and air used as the working fluid is presented in terms of Reynolds number from 8000 - 40000. In the present work, an elliptical rib inserts have been introduced to ascertain the enhanced heat transfer effect and similar investigation was not carried out in the past. The insertion of the elliptical ribs is performed with different intervals of fin to duct height with respected to the main flow direction. These inserts in the ducts are expected to generate a longitudinal vertex flow through the duct. In the experimental study, influence of sixteen fins to duct height ratios for each fin pitch on thermal and flow friction characteristics of the inserted duct have been studied. The experimental results signify that an elliptical inserts provides the highest heat transfer than the plain square duct without inserts. The thermal performance of the newly developed finned elliptical ribs is found to be better than that of the rectangular ribs

Index Terms—Heat transfer, square duct, Reynolds number, Elliptical ribs, Experimental study, friction factor, uniform wall temperature, inserts.

1 INTRODUCTION

Ducts with non circular cross sections are widely used in heat exchangers and other devices. In many instances, designer is faced with existing equipment where the space occupied by the cooling passage is minimal and, the heat and mass flow rates are limited by the size of existing or retrofit pump or fan. In these situations, where coolant passage must be designed so that the volume of the passage is restricted to some value and the heat and mass flow rate of the coolant are dictated by the available equipment. In such cases, non circular duct might be the only option. Augmentation techniques increase convective heat transfer by reducing thermal resistance in heat exchanger.

When air flows through the heat exchanger, the temperature of air may get changed. As a result of the gradual change in the temperature levels in an exchange, the temperature difference across the heat transfer barrier varies over the length of the exchanger. There are various types of swirl/vortex flow generators employed in the heat exchanger ducts such as helical and twisted tapes [1],[2], coiled wires [3], fins/baffles [4],[5] and winglets [6]. The above mentioned swirl flow devices are to circular tubes while the baffle/fin and winglets are suitably employed for the flat surface ducts. The baffle/fin ducts prevents the expansion of the thermal boundary layer and therefore, they increase the heat transfer performance and results in much improved in heat transfer efficiency than the plain duct without baffle/fin .since the realistic importance, the heat transfer and flow characteristics in ducts with baffle/rib/fin swirl flow devices have fascinated numerous investigations. Hirota [7] present an experimental work on the turbulent heat transfer in a square duct; they show detailed characteristics of turbulent flow and temperature field.

Saha and Mallik [8] reported an experimental investigation of the heat transfer and pressure drop characteristics of laminar flow of viscous oil through horizontal rectangular and square plain ducts and ducts inserted with full-length twisted tapes, short length twisted tapes, and regularly spaced twisted-tape elements, under constant heat flux boundary conditions. Pramanik and Saha [9] studied heat transfer and the pressure drop characteristics of laminar flow of viscous oil through rectangular and square ducts with internal transverse rib tabulators on two opposite surfaces of the ducts and fitted with twisted tapes under constant heat flux conditions. As far as ducts of non-circular cross sections are concerned, Sekuli_c [10] and Sahin [11] have presented analyses of irreversibility's associated with ducts of various shapes (namely, circular, square, equilaterally triangular, rectangular and sinusoidal) for laminar flow conditions.

S.Skullong et al. [12] experimentally investigated airflow friction and heat transfer characteristics in a square channel fitted with different rib heights turbulators for the turbulent regime, Reynolds number of 4000-40,000. It was found that the use of in-line ribs provides considerable heat transfer augmentations, Nu/Nu0 = 2.6. Anand Shukla et. al, [13] 2014 An experimental investigation has been carried out with the aim to compare V and ʌ-shaped rib geometry for a square duct to found out rib geometry that gives maximum heat transfer with high value of thermo hydraulic performance. The following conclusions can be drawn from this work: The maximum enhancement in Nusselt number and friction factor values compared to smooth duct are of the order of 3.8 and 8.8 respectively.

2. Experimental Setup

2.1. Apparatus and swirl generator characteristics

The experimental setup consists of 1kW blower is shown in Fig. 1. At room temperature, air flows into test duct through an orifice flow meter and 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 are provided to record the temperature of inlet and outlet test section. The test duct has square cross section of 65x65mm length of 2400mm. The walls of the test duct are hydraulically smooth. Square duct is made up of aluminum all walls of inner duct. In order to maintain isothermal heating condition and with high accuracy, wall temperature distributions were measured over the heated part by 14 thermocouples with ±0.1°C resolution. Control valve is connected to regulate or control flow it is coupled with settling chamber. The outer surface of the test duct was well insulated to lessen convective heat loss to surroundings, and necessary precautions were taken to prevent leakages from the system.

Inside the test section, square duct is inserted and observed temperature readings, mass flow rate, and volume flow rate under constant heat flux condition. Reynolds number, Nusselt number, friction factor and heat transfer coefficient are calculated. In the experiments, it was required to record the temperature, volumetric flow rate and pressure drop of the air at steady state conditions in which the inlet air temperature were maintained at 29°C. All thermocouples are type K and diameter of the wire is 1.5 mm. The thermocouple voltage outputs were fed into a data acquisition system (Fluke 2650A) and then recorded via a personal computer. In this section, the heat transfer rate, Nusselt number, pressure drop, friction factor and thermal performance factor results of the duct with elliptical rib inserts regularly spaced have been investigated.

Nomenclature

A convection heat transfer area of duct, m^2
A_c cross-sectional area, m^2
C_p specific heat capacity of air, J/kgK
D_h hydraulic diameter of duct (=H), m
e ribs height, m
f friction factor
H duct height, m
h average heat transfer coefficient,W/m^2K
k thermal conductivity of air,W/mK
L length of test duct, m
ṁ mass flow rate of air, kg/s
Nu Nusselt number
P rib spacing, m
Δp pressure drop,
Pr Prandtl number
RB ribs blockage ratio, e/H
Re Reynolds number
Q heat transfer, W
T temperature, K
t thickness of ribs , m
U mean velocity, m/s
w width,m

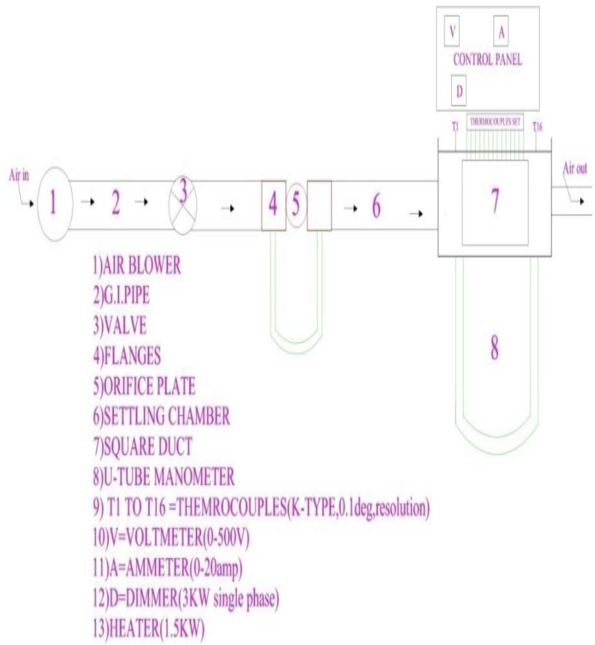

Fig. 1. Proposed experimental setup

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/s)
U air velocity through test section, (m/s)
*T*1, *T*16 - air temperature at inlet and outlet, (°C)
*T*2, *T*3, *T*4, *T*5, T6, T7, T8, T9, T10, T11,T12, T13
T14- Duct wall temperatures, (°C)

Greek letters
ν kinematics viscosity, m^2/s
ρ_a density of air, kg/m^3

3 Data Reduction

The present experiment was conducted to investigate the heat transfer augmentation in a Square Duct inserted with the elliptical rib inserts. The present experimental results on the heat transfer and friction characteristics in a square duct are first analyzed in terms of Nusselt number and friction factor.
The results obtained are displayed in dimensionless terms of Nusselt number and friction factor. The average heat transfer coefficients are calculated by using the experimental data through the following equations:

$$Q_{air} = Q_{conv} = \dot{m}\, Cp(T_0 - T_i)$$

$$h = Q_{conv} / A(\tilde{T}_s - T_i)$$

In which $T_b = (T_0 + T_i)/2$

$$\tilde{T}s = \sum Ts/12$$

Where, A is the heat transfer surface area of duct, Ts is the local surface temperature along the duct length, and Ts is the average surface temperature.
Thus, the average Nusselt number is written as
$Nu = hD_h/k$
The Reynolds number based on the duct hydraulic diameter (D_h) is given by
$Re = UD_h/\nu$
The friction factor is evaluated by

$$f = \frac{2\Delta p}{(I/D_h)/\rho U^2}$$

Where, Δp is the pressure drop across the test duct and U is the mean air velocity in the duct. All properties of air are evaluated at the overall bulk air temperature.

4. Results And Discussion

4.1. Validation of smooth square duct

The experimental results of Nusselt number and friction factor obtained. From the present plain

Square duct are compared with those from correlations of Dittus–Boelter, Blasius and Petukhov found in Ref. [14] for turbulent flow in ducts.

Correlation of Dittus-Boelter,

$Nu = 0:023\ Re^{0.8} Pr^{0.4}$ for heating (1)

Correlation of Blasius,

$f = .0316\ Re^{-0.25}$ $3000 \leq Re \leq 20{,}000$ (2)

Correlation of Petukhov,

$f = 0.79\ (\ln Re - 1:64)^{-2}$ (3)

The comparison of Nusselt number and friction factor obtained from the present plain square duct with those from correlations of Eqs. (1), (2),(3) are presented.

4.2. Heat transfer rate and Friction factor behavior of Duct with inserts

The present results on the heat transfer and friction factor in a uniform heat-fluxed square duct with elliptical rib inserts are presented in respectively, terms of Nusselt number (Nu) and friction factor (f) against Reynolds number as depicted in Figs 2 and 3. In Fig.2, the Elliptical rib inserts Nusselt number is increased more than the plain Square duct which means higher heat transfer rate has been obtained in elliptical rib inserts rather than

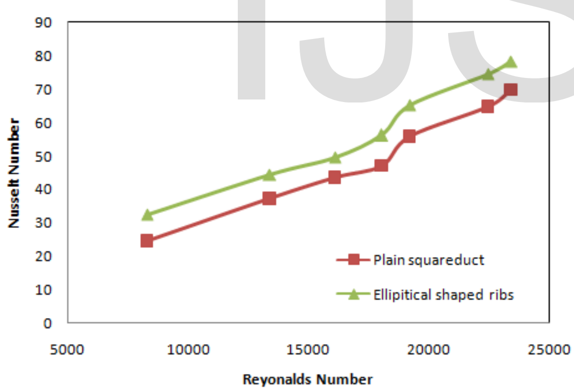

Fig. 2. Relationship between Nusselt Number and Reynolds Number

the plain Square Duct. Therefore, inserted duct yields the considerable heat transfer enhancement with similar trend pattern in comparison with the plain square duct.

It is visible in Fig. 3 that the use of the Elliptical rib inserts leads to a substantial increase in f above the smooth duct and the f shows the decreasing tendency with the increment of Reynolds number.

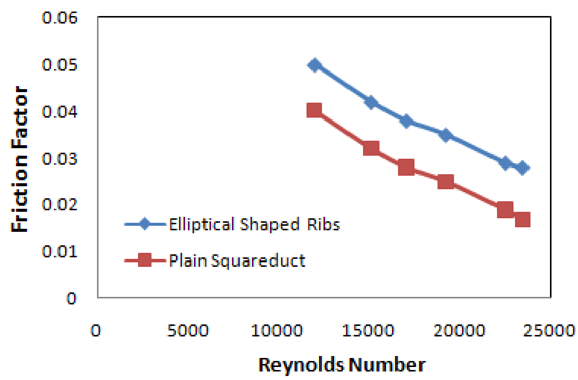

Fig. 3. Relationship between Reynolds Number and Friction Factor

4.3. Effect of velocity on heat transfer

The heat transfer coefficient is increased along with the velocity increases both plain duct and

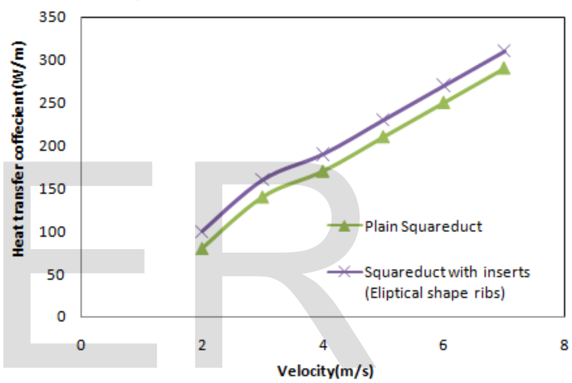

Fig. 4. Effect of Velocity and Heat transfer coefficient

Duct with inserts. The vortex flows could wash up the flow trapped in the duct corner regions normally act as ineffective heat transfer areas, leading to higher heat transfer rate in the duct.

5 Conclusions

An experimental investigation on heat transfer and friction factor characteristics in a uniform heat flux square duct with elliptical rib inserts at different velocities for turbulent air flow, Reynolds number from 8000 to 40,00 has been conducted. The elliptical inserts provide a significant effect on the change of flow direction in the duct leading to the considerable increase in both heat transfer and pressure drop. It is observed that experimental heat transfer coefficient increases by inserting the ribs. Based on the experimental results, it was found that how ducts are to be used more effectively and also the inserts are to be influenced to increase the Nusselt number and Reynolds number which in turns to influence reduce the expensive cost of the equipment..

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