Effect of inserts in square duct heat exchanger under Turbulent flow

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Abstract—: An investigational work has been carried out to find out pressure drop and warmth transfer uniqueness for unstable flow through square duct heat exchanger with V Shaped inserts .in this experimentation air is considered as working fluid , which is passed through duct under constant surface heat-flux conditions. The design of duct and V shaped inserts are fabricated. The experimental evaluation for V –shaped inserts are analyzed at various parameters and compared with plain square duct. Analyzation takes place in terms of number Nusselt number , Reynolds number and Prandtl number. During this experimentation, it has been observed that The Nusselt numbers for the V Shaped inserts with various parameters are in the range of 1 56 - 2.63 times above the square duct.

Keywords— V Shaped inserts,Nusselt number, Reynolds number ,heat transfer,square duct, Turbulentflow.

I. INTRODUCTION

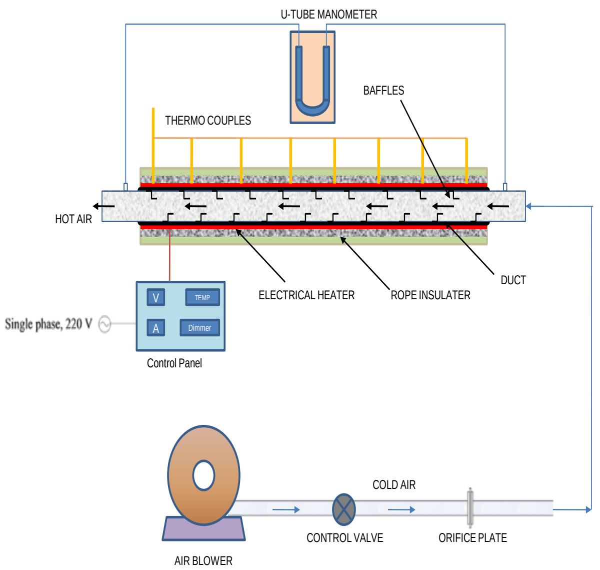
Various augmentation techniques have been widely used to improve heat transfer in diverse engineering and industrial applications such as: heat exchangers , refrigeration and air conditioning,, processed industries gas cooled nuclear reactor, etc. As the preceding works, there are found that the uses of the vortex generators were placed on the duct wall or on the channel wall. The vortex generators which placed on the tested walls were difficult to forming and installing. It has always performed a small gap between tested wall and the vortex generators. Therefore, the modified vortex generators are appropriate and trouble-free to install are important to investigate. Except from the installation vortex generators, the L shaped Baffles which provide a higher heat transfer rate and the thermal performance were found. The L shaped baffle vortex generators perform higher heat transfer rate and the thermal performance in comparison with other shapes such as inclined baffle. Therefore, this work will be focused on the installation method for the L shaped baffle vortex generators in the heat exchanger square duct. The experimental results of assorted turbulators in flat plate-fin heat exchanger were reported by Gentry and Jacobi, 1997;[1] Chen and Shu, 2004,[2] and Wu and Tao, 2012[3]. They concluded that the use of turbulators in the heat exchanger lead to increase heat transfer and thermal performance in the heat system. The L shaped baffles are placed on both sides of a duct and maintain equidistant in the square duct. Moreover, to reduce the pressure loss that is done by inserted thin plate, the design of the wire frame for installing l–shaped baffle diagonally is studied. The effects of the blockage ratio, pitch ratio, flow direction and Reynolds number are presented.

Among significant studies, Tsay et al[4] experimentally investigated that , by considering the thickness ,height of the baffle, on a vertical baffle in backward facing step(stride) flow channel. They have been observed that inserting a baffle into the flow the Average Nusselt number increased by 180%.Berner et al[5]. Obtained experimental result of turbulent distribution and mean velocity in flow around segmented baffles. Experimental investigation of the turbulent flow and heat transfer characteristics inside the periodic cell formed between segmented baffles staggered in a rectangular duct was studied by Habib et al[6]. Mathematical calculations of the flow and heat transfer in square channel with staggered fins were investigated by Webb and Ramadhyani[7], Kelkar and Patankar[8], and Habib et al[9].Investigational study of Dutta and Dutta[10] on perforated baffles illustrates enhanced in heat transfer with perforations compared to solid baffles, if the plate is inserted on to the surface of the heated duct and aptly arranged in the direction of the flow. By using baffles or fins on the surface of the ducts Heat transfer surface area may be improved [11] . Turbulent flow and heat transfer through pipes and annuli with longitudinal internal fins were analyzed by Patankar *et al*. [12]. Al-Arabi [13] studied the variation of heat transfer in a tube under the forced convection at entrance condition.. El-Sayed *et al*. [14] reported experimentally to determine the pressure drop characteristics of flow inside circular tube. Tijing *et al*. [15]were performed experiment and investigated the effect of straight and twisted internal fins on augmentation of heat transfer.

II. EXPERIMENTAL SET UP AND PROCEDURE

The experimental setup used to study as shown in Fig 1. The experimental apparatus consists of 1 KW blower, air at a room temperature flows into test square duct through orifice flow meter and a settling chamber. water was used in U-tube vertical manometer to ensure practicallycorrect measurement of the pressure .The tested square duct has cross sectional area of 65x65 mm, length of 2400 mm. The apparatus of the experimental setup are air blower, Aluminum square duct, nichrome heater, GI pipe, control valves, orifice plate, U tube differential manometer, dimmer stat, K type thermocouples and data logger as shown in Fig. 1. the square duct is made of aluminum material with hydraulic diameter of 65mm, thickness of the duct is 3mm.Baffles were made from Aluminum of thickness 0.8mm and height 40mm. In order to measure surface temperatures , inlet and outlet temperatures The K type copper constantan thermo- couples with .0.1

degree resolution were used to measure the surface temperatures, inlet and outlet temperatures . The test section was heated by using Nichrome wire to provide uniform heat flux boundary condition .The electrical output was restricted by variac transformer to obtain heat flux along entire length of the test section .To restrict current flow to test section the test section was covered by rope insulation tape and Nichrome wire was found over it. To minimize heat loss to the surroundings due to convection a layer of asbestos wool is wrapped over the square duct. velocity of air was measured by anemometer. The control valve was provided to change the flow rate of air. In this experimental analysis, volume flow rate, temperatures and pressure drop were recorded under stead state conditions and also inlet temperature was maintained at 25.6 degree centigrade. The range of Reynolds number varied between 10,000 to 30000.Thel wall temperature (T_w) , inlet and outlet air temperatures , airflow velocity were measured for heat transfer of the heated square duct with baffle inserts, and also calculate Nusselt number,Reynolds number, friction factor, heat transfer coefficient.



Schematic Diagram of experimental system

Nomenclature

A- heat transfer area of square duct, m^2
A_c- cross-sectional area of duct, m^2
C_p -specific heat of air, J/kgK
D_h -hydraulic diameter of square duct , m
e -baffles height, m
f -friction factor
H – square duct height, m
A_o - orifice meter area(m^2)
C_d -coefficient of discharge of orifice meter
ΔP -pressure drop across test section (P_a)
ΔP_o -pressure drop across orifice plate(P_a)
h -heat transfer coefficient,W/m^2K
k -thermal conductivity of air,W/mK
L -length of tested square duct, m
ṁ - mass flow rate of air, kg/s
Nu -Nusselt number
Pr -Prandtl number
Re -Reynolds number
Q -heat transfer, W
T -temperature, K
t -thickness of baffles , m
W -width, m
T_s -average Surface temperature of the working fluid, (°C)
T_b -bulk temperature, (°C)
V -velocity of flow of air (m/s)
U -air velocity through test section, (m/s)
T_0,T_i - temperatures of air at inlet and outlet, (°C)
T1,T2, T3, T4, T5, T6, T7, T8, T9, T10, T11,T12, T13,T14,T15,T16 - Duct surface temperatures, (°C)
H_w=height of water column(m)

Greek symbols

ν -kinematics viscosity, m^2/s
ρ_a -density of air, kg/m^3
δ -thickness of aluminum sheet, mm

III. DATA REDUCTION

The unprocessed experimental data have been abridged to get hold of the mean, surface temperatures, mass flow rate and Reynolds number. The values were obtained used to estimate ,Nusselt number, friction factor and heat transfer coefficient. The heat transfer coefficient can be calculated as flows

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

The experimental investigation was conducted to study the heat transfer rise in a Square Duct with the baffles as inserts. In this experimental investigation results on heat transfer and friction factor characteristics in tested square duct with baffles as inserts are estimated in terms of Nusselt number and friction factor .

With the help of the governing equation and considering the experimental values . the under mentioned equations have been used to calculate heat transfer coefficient

Height of air column is given by $H_{air} = H_w (\rho_{air}/\rho_{water} - 1)$

Velocity of air = $V_{air} = Cd\sqrt{2 g H_{air}}$

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

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

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

$\tilde{T}s = \sum Ts/14$

Where, A area of the square duct, T_s is the average surface temperature.

Thus, the Nusselt number is calculated

$Nu = hD_h/k$

The Reynolds number (D_h) is given by

$Re = UD_h/\nu$

The friction factor is evaluated by

The friction factor is determined by using the Darcy–Wiesbach equation as

$f = \frac{2\Delta p}{\quad}$

$(l/D_h)/\rho U^2$

Where, Δp is the pressure drop throughout the tested square duct. U is the velocity flow of air in the tested square duct. All properties of air are evaluated at the mean bulk air temperature.

Mass flow rate of air has been estimated from the following equation

$\dot{m} = C_d A_o [\ 2\ \rho_{air} \Delta p_o] / [1-\psi^4]$

The rise of air temperature along the square duct is not very high and thermal properties fluids being well documented .Therefore uncertainties in fluid properties variation have been neglected without much loss in accuracy.

IV. RESULTS AND DISCUSSIONS

After completion of this experiment all the readings are noted and calculations have been completed and comparative graphs are plotted related to the calculations .

4.1. Validation of plain 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 for turbulent flow in ducts as shown in Fig 2(a) and (b).

Correlation of Dittus-Boelter,

$Nu = 0:023\ Re^{0:8}\ Pr^{0:4}$ for heating (1)

Correlation of Blasius,

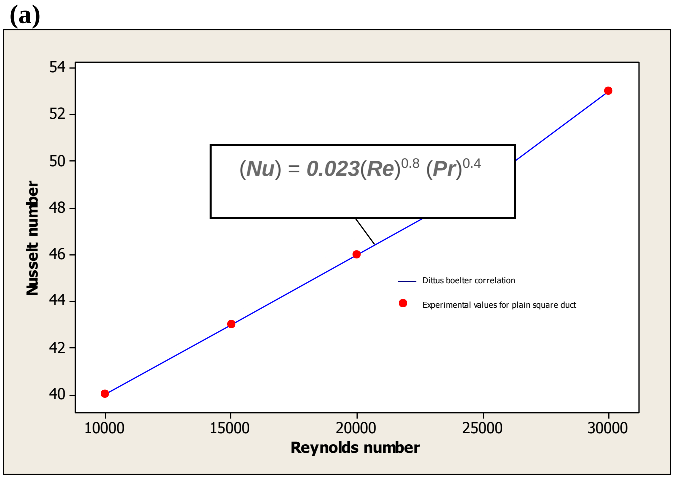
$f = .0316\ Re^{-0.25}$ $3000 \leq Re \leq 20{,}000$(2)

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.

(a)



(b)

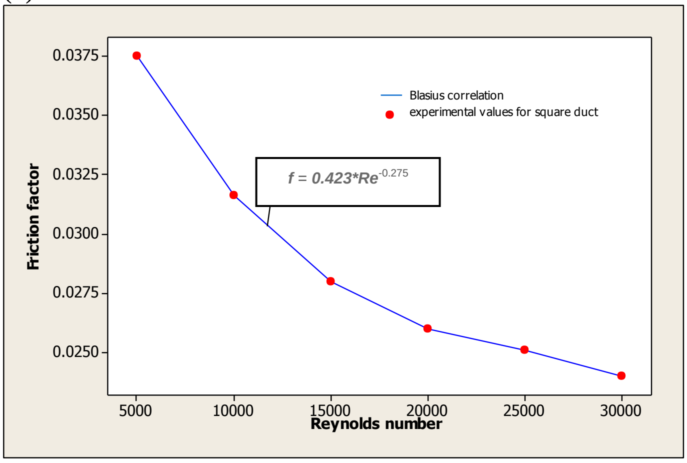


Fig 2 verification of (a) Nu and (b)f for plain square duct

In the above figs displays Nusselt number increase with increases of Reynolds number and also validated with standard correlation. Similarly friction factor decreases along with Reynold number increases.

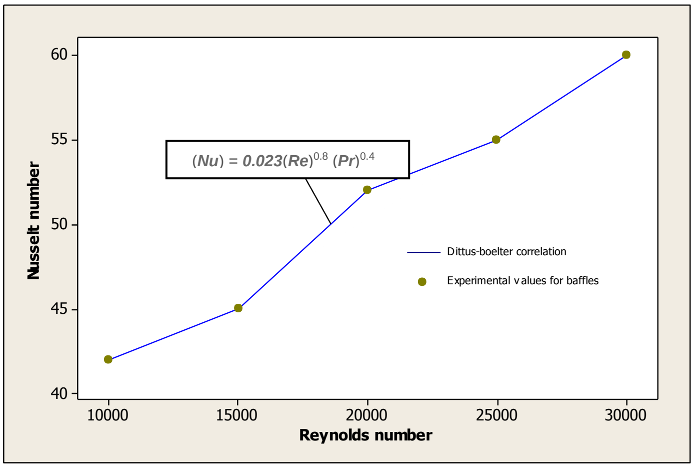


Fig3 Effect of Baffle on Nu vs Re

It is clear from the figure3, the Nusselt number increases as Reynolds number increases and the heat transfer enhancement is about 2.8 to 3.9 times than that of plain square duct. The structure of secondary flow by the baffles are mainly responsible for the increase in heat transfer coefficient.

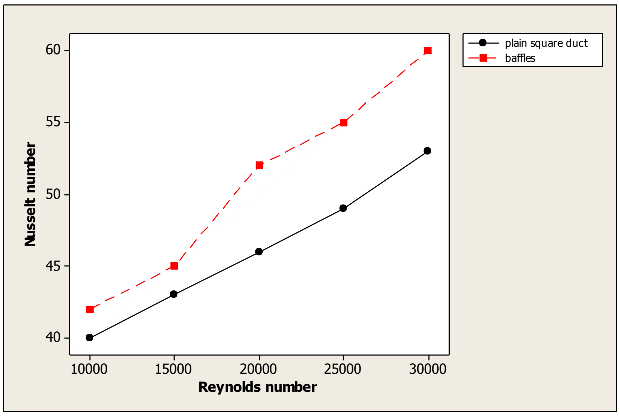


Fig4 Variation of Nu with Re for plain square duct and Baffle arrangement

It was found that the Nusselt number increase with increase in Reynolds number. The variation is shown in the graph with respect to different Re and Nu number. In this case Baffle inserts are placed onto the square channel and then it arranged periodically. It has been observed that there is more enhancement was obtained with the help of Baffle inserts in the square duct.

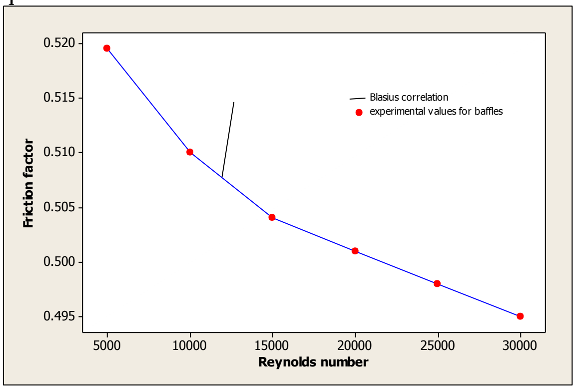


Fig 5 Effect of f with Re for Baffles arrangement.

It is visible in Fig5 that the use of the Baffles as 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 and it remains almost constant at higher Reynolds numbers.

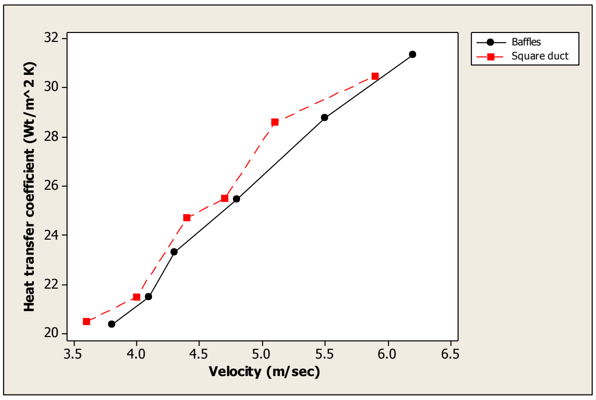


Fig 6: Variation of Heat transfer coefficient with velocity for and Plain square duct.

It reveals that velocity of air flow increases along with the heat transfer coefficient.for plain square duct. Similarly inserting Baffles into the Square duct heat transfer coefficient further increased as compared to the plain square duct.

V. CONCLUSION

The experimental setup is validated with Dittus-Boelter and Blasius corelation.

An experimental investigation on heat transfer and friction factor characteristics in a uniform heat flux square duct with baffles as inserts at different velocities for turbulent air flow, Reynolds number from 10000 to 30,000 has been conducted. The baffles are providing a significant effect on the change of flow direction in the duct leading to the considerable increase in Nusselt number as well as heat transfer. It is concluded that V shaped Baffles are having more heat transfer coefficient, which is 32% higher than that of plain square duct,

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. .As the Reynolds's number increases, higher heat transfer rates are observed regardless of the position of the baffles. From these results it can be also concluded that system is more effective in case of inserts as compared to the case of without inserts. The simultaneous effect of both the heat transfer and friction factor was taken into consideration in the present study and thus the study is based on higher heat transfer rate with minimum friction factor. The maximum enhancement in Nusselt number and friction factor values compared to smooth duct are of the order of 3.6 and 8.7 respectively.

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