Effect of Dimpled Surface with Straight Spoiler Turbulators on Heat Transfer and Fluid Flow Characteristics for Channel

Sandeep S Kore, Sunil Dambhare, Rupesh Yadav, Firoz Pathan, Shrikant Nawale

Abstract: An experimental investigation has been carried out for heat transfer enhancement over dimpled surface using spoiler turbulators. The experimentation is carried out over the aluminum plate of 1000 mm x 10 mm x 5 mm and Reynolds number ranging from 10,000 to 33,000. The δ/d ratio for dimple is 0.3, which is kept constant. The pitch for dimples are varied as 16 mm, 18 mm and 20 mm. Turbulators were used over the dimples surface in inline and staggered arrangement which provides different flow structure and produces turbulence. Turbulators are mounted over dimples at an angle of 12^{o} with respect to flat plate. Experimental results were validated using Dittus-Boelter and Blasius equations. Analysis is made using Nusselt number, friction factor and performance index. It has been found that compared to dimpled plate performance of dimpled surface with spoiler tabulator plate is higher. If we compare inline and staggered arrangement, performance of inline arrangement dimple plate with turbulator is higher compared to staggered arrangement. This is due to in staggered arrangement at some locations chocking of flow may takes place which reduces heat transfer rate.

Index Terms*: *Vortex generator, Dimple surface, Spoiler turbulators, Heat transfer enhancement

I. INTRODUCTION

During recent years, the study of heat transfer enhancement has gained serious momentum due to increased demand for heat exchange equipment that is less expensive to build and operate. Dimple surfaces increases the heat transfer coefficient due to its flow structure produced. Dimples are of spherical shape used by number of researchers. In the present study spherical dimple with diameter 10 mm is used. Diameter of the dimple is constant throughout the experimentation. The δ/d (dimple depth to dimple diameter) ratio is 0.3, kept constant. However, dimple with different pitches such as 16, 18, 20 mm has been experimented. The dimpled surface is o f special shape used for improving the heat transfer rates without the significant pressure drop [2]. Normally the dimple generates the vortex flow within its cavity and the augmentation of heat transfer is obtained. Turbulators are used to provide artificial roughness which gives interruption in the flow path to promote turbulence. Turbulators are made up of aluminum sheet of 0.5 mm thickness and are mounted over the dimple plate. The arrangement of turbulators were made inline and staggered type [1]. The flow of air is allowed to pass over the arrangement of dimple and turbulators. The flow gets split by turbulators into two parts i.e. primary flow and secondary flow. The primary flow gets directed towards dimple thus causing vortex generation. The secondary flow passes over turbulators. Primary flow and secondary flow mixes with each other results in increased heat transfer rates. This cycle repeats for every turbulators and dimple arrangement thus enhancing heat transfer rate. Providing roughness elements in higher friction factor and Nusselt number. This technique of heat transfer can be used in gas cooled reactors, automobile radiator, internal surface of pipes, heat exchanger, electric applications, solar air heaters.

II. EXPERIMENTAL DETAILS

The experimental setup and details are shown in Fig.1

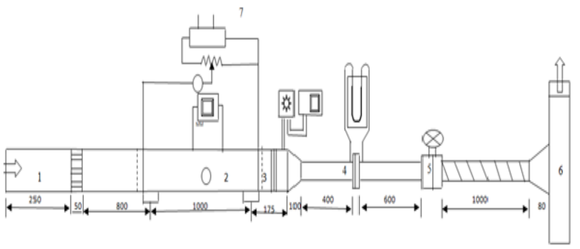

Fig.1 Experimental set up

The setup for experimentation is assembled to find out the enhancement takes place in heat transfer and fluid flow characteristics in a rectangular duct. The test apparatus consists of an inlet section (1), test section (2), mixing chamber (3), orifice (4), flow control valve (5), centrifugal blower (6). The test plates are of 1000 mm x 100 mm x 5 mm. It has been mounted on a rectangular plenum of 1000 mm x 100 mm x 25 mm. The inlet section has length mm of 250 mm and mixing chamber has length of 400 mm. A heater of capacity 1000 W is used To provide uniform heat flux boundary condition. The whole arrangement is wound with asbestos rope, glass wool, aluminium foil. This layer of insulators prevents the heat losses and provides more accurate results of the experiment. Orifice is used to measure the mass flow rate of the air and flow rate is controlled by flow control valve. The U tube manometer is used to measure pressure drop across the orifice. Water is used as manometric fluid. Thermocouples are placed at uniform distance to measure the temperature of test plate.

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Thermocouples are of T-type made up of copper constantan. Nine thermocouples are provided across test plate to measure the temperature of the plate. Two thermocouples are provided to measure air inlet and outlet temperature. One thermocouple located at inlet of the test section and other at exit section i.e. after the mixing chamber. The thermocouples are connected to the temperature indicator which gives output in degree Celsius.

In flow structure developed is as shown in Fig.2. Air is allowed to flow over hot dimpled surface having spoiler turbulator. The flow of air is split into two parts by turbulators viz. primary flow and secondary flow. Primary flow is directed towards dimple with higher velocity which helps to reduce the low heat transfer zone formed at the leading edge of the dimple. Thus number of cutting edges of spoiler turbulators creates low pressure penalty as compared to solid ribs. Combination of dimple and spoiler turbulators prevents formation of eddies inside the dimple and redevelopment of two boundary layers takes place at the training edge of the dimple.

The number of cutting edges of the spoiler turbulator shears more viscous sub-layer. Two horizontal inclined edges can form two shear layers which cause mixing of primary and secondary flow and create turbulence. Four side legs leads to formation of secondary flow which causes interruption to growth of boundary layer which causes heat transfer enhancement. Due to recombining of primary and secondary flow, heat is transferred from primary to secondary flow. This pattern is repeated and strengthened the flow causes more mixing of primary and secondary flow enhances heat transfer rate.

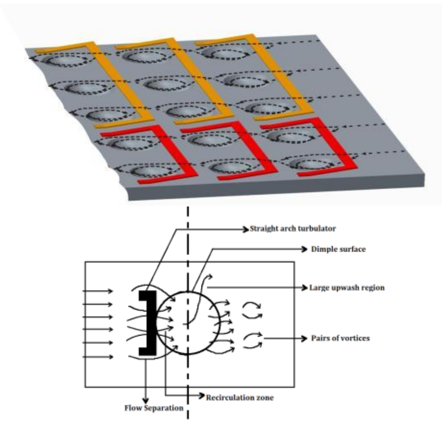

Fig.2 Dimpled surface with spoiler turbulator and flow structure

III. METHODOLOGY

The maximum flow rate is measured by using following expresion which gives relation between maximum flow rate and pressure drop.

$$\dot{m} = C_d \times \left(\frac{\pi}{4}\right) \times d_0^2 \times \rho_0 \times \sqrt{\frac{2gh}{1-\beta^4}} \qquad (1)$$

where,

C_d=coefficient of discharge of orifice meter

d_0 =orifice diameter

β=ratio of diameter of orifice to diameter of pipe

ρ_0=density of air

h=height of air column

The usefull heat gain is given by

$$Q = \dot{m} \times C_p \times (T_e - T_a) \qquad (2)$$

where,

T_e = Exit temperature of air

T_a = Inlet temperature of air

Heat transfer coefficient is calculated by

$$Q = h \times A \times (T_s - T_{bm}) \qquad (3)$$

where,

T_s= Steady state temperature of plate

T_{bm}=mean temperature of air inlet and outlet

The Nusselt number is calculated by

$$Nu = \frac{h \times D_h}{k_{air}} \qquad (4)$$

Friction factor is calculated by

$$f = \frac{dp \times D_h}{2 \times \rho_{air} \times L \times V_{air}^2} \qquad (5)$$

Thermal performance is calculated by

$$\text{Performance index} = \frac{\frac{Nu}{Nuo}}{\left(\frac{f}{f0}\right)^{\frac{1}{3}}} \qquad (6)$$

IV. E EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Validation of Experimental set up

The experimental set up is validated for plain duct with available correlations from the literature. The validation is done for heat transfer and friction. The Nusselt number compared with values obtained from Dittus-Boelter correlation. The friction factor compared with Blasius correlation.

Dittus-Boelter Equation:

$$Nu_s = 0.023 \times Re^{0.8} \times Pr^{0.4} \qquad (7)$$

Blasius Equation:

$$f_s = 0.0791 \times Re^{-0.25} \qquad (8)$$

Average percentage deviation is ±9.4%. for Nusselt number and for friction factor it is ±11.5%.

B. Heat Transfer and Friction Factor characteristics

Figure 3 shows the variation of normalized Nusselt number for dimpled plate with spoiler turbulator for different pitch like 16, 18 and 20 mm.

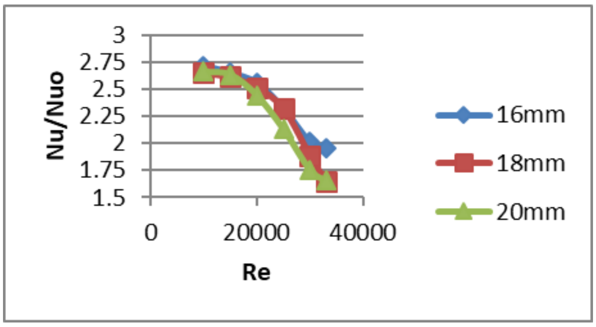

Fig. 3: Nu/Nu_o Vs. Re for inline arrangement of Turbulators

The arrangement of turbulators over a dimpled surface consists of inline and staggered arrangement. The value of Nusselt number is found to be maximum at Re=10000(Nu/Nu_O =3.13) for p=16 mm.

It is also found Nu/Nu_o ratio decreases as Reynolds number increases beyond 10000 for all pitch of turbulators. Among the pitches considered in experiment, p=16mm is found to be more efficient as compared to rest (p=18mm and p=20mm.) The reason for this is higher surface area due to higher number of dimple on p=16mm plate.

Figure 4 shows, the variation of friction factor with Reynolds number for 16 mm, 18 mm, and 20 mm pitch arrangements of turbulators.

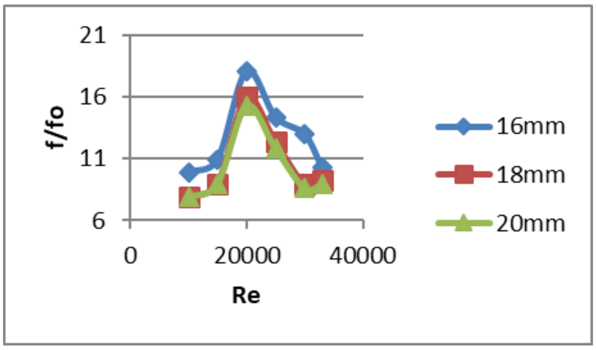

Fig. 4 Variation of f/f_o Vs. Re for inline arrangement of Turbulators

It is found that friction factor is higher for p=16 mm and lower for p = 20 mm for Re = 33000. The nature of the curve is found to be increasing with increase in Reynolds number. The maximum value of friction factor is found to be 1.86 times the flat plate surface for inline arrangement of inverted U-turbulators over dimple plate surface for p=16mm. The increase in friction factor for p=16mm is found to be appreciable due to higher resistance produced by higher number of turbulators compared to other pitches.

After Re=10,000 the friction factor increases due to transitional flow where more eddies are formed. Friction factor is maximum at Re=20,000 then decreases.

Figure 5 indicates the variation of Nu for dimple plate with spoiler turbulator with respect to flat plate against Reynolds number for p=16,18 and 20mm. The spoiler turbulator is kept in staggered arrangement. The value of Nusselt number is found to be maximum at Re=10000 (Nu/Nu_0= 2.89) for p=16 mm which is less than inline arrangement.

It is also found that Nu/Nu_0 ratio decreases as Reynolds number increases beyond 10000 for all pitch of turbulator considered. Amongst all pitches considered in experiment, p=16mm is found to be more efficient as compared to rest one as seen in inline arrangement.

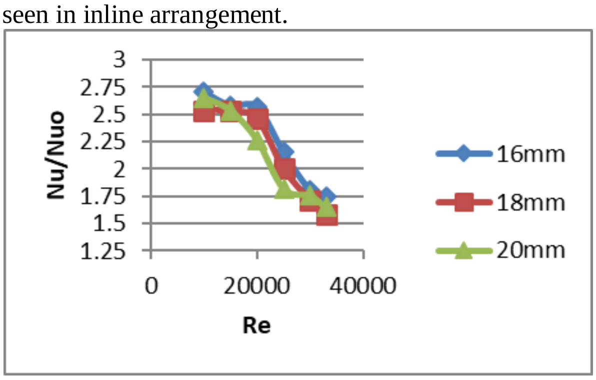

Fig. 5 Nu/Nu_o Vs. Re for staggered arrangement of turbulators

Figure 6 shows the variation of friction factor with Reynolds number p=16, 18,20 mm for staggered arrangement. Again it is found that friction factor is higher for p=16mm and lower for p=20 mm for Reynolds number of 33,000. The nature of the curve is found to be increasing with increase in Reynolds number. The maximum value of friction factor is found to be 1.86 times the flat plate surface for staggered arrangement of spoiler turbulators over dimple plate surface for p=16mm.

Amongst the two arrangement of turbulator i.e. inline and staggered, inline is found to be more efficient in terms of heat transfer with slightly higher friction factor compared to staggered arrangement

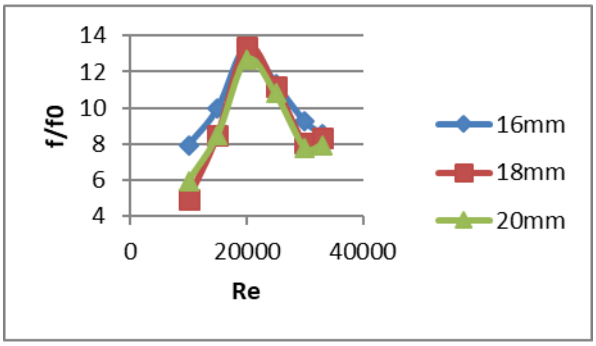

Fig. 6 f/f_o Vs. Re for staggered arrangement of turbulators

C. Thermo hydraulic performance

Figure 7 and Fig. 8 shows thermo-hydraulic performance for inline and staggered arrangements of turbulators over dimple plate surface respectively. The curve is plotted for performance index against Reynolds number for p=16, 18, 20mm. Performance index is found to be greater for p=20mm for inline arrangement while lower for p=18mm. Similarly for staggered arrangement, Performance index is found to be greater for p=16mm and lower for p=20mm respectively. The nature of curve is found to be decreases in both arrangements as Reynolds number increases. Performance index is found to be similar for all pitch variation for both arrangements for Reynolds number range between 25,000-33,000. The highest value of Performance index is found to be 1.6 for p=20 mm for staggered arrangement.

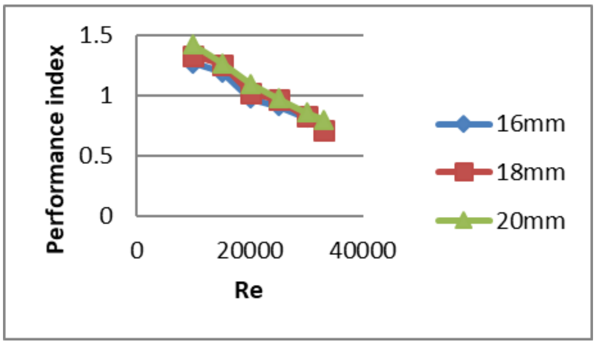

Fig. 7 Performance index Vs. Re for inline arrangement of turbulators

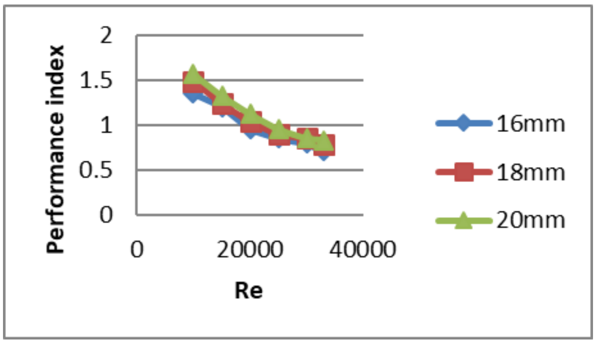

Fig. 8: Performance index Vs. Re for Staggered arrangement of turbulators

V. CONCLUSION

An experimental investigation of flow of air over heated dimple plate surface with different arrangement of spoiler turbulator has been performed. The effects of Reynolds number, pitch of dimple, arrangement of turbulators on heat transfer coefficient, friction factor and Performance index has been studied. Experimental results has been compared with flat plate surface to find out augmentation in heat transfer coefficient and friction factor. The range of raynold number found to be 10000-33000. Following conclusions have been made:

- Dimple plate strongly affects the flow pattern and heat enhancement rate. Dimple pitch p=16mm is found to be more efficient than compared to other pitches.
- Turbulator arrangement is found to be effective on heat enhancement performance. Inline arrangement of turbulators is found to be more efficient than staggered arrangement.
- Dimple surface with spoiler turbulators in inline arrangement for p=16mm is found to be highly effective in terms of heat transfer coefficient amongst all considered arrangement with different pitch. The maximum enhancement in Nusselt number and friction factor values compared to flat plate surface for inline 16mm pitch and for Re=10000.
- Thermo hydraulic performance is found to maximum for p = 20 mm for inline arrangement of turbulators.

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