Heat Transfer and Friction Factor in a Circular Tube Fitted with Ring Sector

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Abstract—The use of ring sector insert as vortex generator for heat transfer enhancement in pipe flow has been investigated in this paper. The typical inserts were fabricated with central rod. The projections of ring sectors were attached to the central rod while the ring sectors were just touching the circular wall. The measurements of heat transfer enhancement and pressure drop was carried out for different axial pitch distance between ring sectors and flow angle of attack. The performance has been evaluated in terms of Nusselt number ratio based on equal Reynolds number (Nu/Nus). Similarly the friction factor ratio based on equal Reynolds number criteria has been presented as f/fs. The results obtained are discussed in this paper for the Reynolds number ranging from 8000 to 17000.

Keywords—Angle of attack, Friction factor; Ring sector, Vortex generator.

I. INTRODUCTION

The heat exchanger performance is always limited to the gas side as heat transfer coefficient is inherently lower for gas side than for liquid or two phase flow. This limitation of low heat transfer coefficient for gas and the desire to improve energy performance with reduced volume and manufacturing cost continues to motivate the research in gas side heat transfer enhancement. There is demand for high performance heat exchanger devices for application in small size and light weight heat exchanger. Apart from this other objectives are optimization of capital and operating cost. Both can be positively affected by either increasing the heat transfer coefficient or by increasing effective heat transfer surface area per volume or both. Heat transfer enhancement using inserts always gives penalty in terms of pressure drop. For heat transfer enhancement in circular tube, inserts are the most popular since they are very easy to install and do not required deformation of material on the inside surface of the tube. Twisted taps and wire coil inserts are the most widely used inserts.

Webb et al [1] studied characteristics of rib roughness in turbulent pipe flow. It was investigated that repeated rib surface might be viewed as a problem in boundary layer separation and reattachment. Separation occurs at the rib forming a widening free shear layer which reattaches at 6-8 rib height downstream from separation point. A maximum heat transfer coefficient occurs in the vicinity of the reattachment point. The local heat transfer coefficients in the separation flow region are larger than those of an undisturbed boundary layer. Brockmeir et al[2] investigated five different types of plate channel heat exchanger each showing the typical plate fin surface for gases. These are plane fin exchanger surface with rectangular cross section, plane fin exchanger with triangular cross section, offset strip fin exchanger surface, louvered fin exchanger surface and vortex generator surface. In this analysis it was observed that vortex generator surface provide larger saving in heat exchanger’s surface area and thus in heat exchanger’s volume. Manglik & Bergles [3] have developed heat transfer and pressure drop correlations for laminar & turbulent regimes with twisted tapes as inserts. The development of correlation is based on a variety of effects. These effects are increase in flow velocity, decrease in hydraulic diameters, increase in helical flow path of the particle, secondary motion generated by tape & fin contribution if tape & tube is in good thermal contact. Eiamsaard et al[4] investigated heat transfer and friction characteristics in a horizontal double pipe heat exchanger with & without twisted tape inserts. It is observed that a single continuous tape gives the best heat transfer enhancement than discontinuous strips of tape as inserts. Naphon et al [5] carried out experiment with twisted taped. He reported that lower the ratio of pitch of twisted tape to diameter higher is the heat transfer rate. Raja Rao et al[6] reported heat transfer data for wire coil insert and suggested correlation for the same. Wang et al [7] presented comparison of performance for twisted tape & wire coil insert. It was concluded that wire coil inserts provide better overall enhancement performance than twisted tape inserts for same helix angle & thickness ratio as wire coil insert provide much less pressure drop penalty than twisted tape inserts. Fiebig et al [8] had used vortex generators (VGs) for heat transfer enhancement over flat surfaces. They compared performance of different VGs-namely delta wing, rectangular wing, delta-winglet pair and rectangular winglet pair. They reported that delta wings gives the highest heat transfer enhancement per unit area. Yakul et al[9] used tape with delta-winglets-VGs on both sides of the tape insert in round tube. They reported that Nusselt number increases slightly by increasing height of winglet, but friction factor increases sharply by increasing height of winglet & angle of attack.

The objective of the current work is to study the use of ring sector as VGs for heat transfer enhancement in tubes. The use of VGs for heat transfer enhancement in rectangular channel is popular, but very few literature is available on use of VGs in circular tube. Here our attempt is to get high heat transfer enhancement in circular tube using ring sector inserts as VGs.
enhancement with less pressure drop penalty. For this purpose specially designed insert assembly was used and results are obtained for constant Reynolds number.

II. EXPERIMENTAL SET UP

An experimental test facility is constructed to measure the heat transfer coefficient in smooth tube & tube fitted with ring sector. The sketch of test facility is as shown in fig.(1) and photograph of experimental set up is as shown in fig. (2).

Air as working fluid is forced into test section by using blower (6). The flow rate of air in the test section is controlled by regulating inlet valve. The mass flow rate & velocity of air in test section is measured by venturimeter (4) placed before the inlet of test section. Two pressure taps attached at the inlet and throat of venturimeter are connected to U-Tube manometer (5) containing water as manometer fluid to measure differential pressure head across the venturimeter. The pressure drop across the test section (8) is measured by pressure taps across the inlet and outlet of the test section which are connected to U-Tube manometer containing water as manometric fluid. The test section is 1000 mm long stainless steel tube of wall thickness 0.25 mm & 25 mm outside diameter. A nicrom wire (7) is wound around the test section. It is covered with cotton to avoid heat loss to the surrounding. The regulated power is supplied to the wire through dimmer which provide uniform heat flux to the test section. The bulk temperature of inlet and outlet flow of air in test section is measured by precalibrated thermocouples (1).

The geometry of typical ring sector is as shown in fig.3 (a) and fig.3 (b) shows tube fitted with ring sectors.

The ring sector has been designed to confirm to the circular geometry of test section. They are made up of 0.25 mm thick aluminum sheets. The ring sector is cut from the circle of diameter (D) 12.5 mm. They are attached on 3 mm stainless steel rod at a specified axial location & at a particular angle of attack to the flow direction.

The friction factor \( f \) is determined in terms of the pressure drop \( \Delta P \) across the test section length \( l \) & mass velocity \( v \) of air with density \( \rho \) as

\[
f = \frac{\Delta P}{\rho(l/D)v^2/2}
\]  

(1)

The friction factor is based on actual experimental conditions.

Heat carried \( q \) by air flow from the test section is determined in terms of mass flow rate of air \( m \), specific heat of air at constant pressure \( c_p \) , inlet temperature of air \( T_1 \) and outlet temperature of air \( T_o \) as

\[
q = m c_p (T_o-T_1)
\]  

(2)

Average heat transfer coefficient \( h \) based on net heat transfer rate \( q \) and surface area \( A_s \) is given by
\[ h = \frac{q}{A_s(T_o - T_i)} \]  

(3)

The Nusselt number (\( Nu \)) for fully developed flow for the test section with inserts is calculated in terms of heat transfer coefficient, diameter of tube (\( D \)) and thermal conductivity of air (\( k \)) as

\[ Nu = \frac{hD}{k} \]  

(4)

The experiment have been performed for different Reynolds number, pitch to diameter ratio & angle of attack.

The heat transfer coefficient enhancement is reported in the form of the ratio of the measured Nusselt number to corresponding smooth tube Nusselt number at given Reynolds number (\( Nu/Nus \)).

### III. RESULT

As the air flows through tube, the hydraulic diameter was taken as tube diameter. The flow was fully developed. Only the variation of axial pitch distance between ring sectors and flow angle of attack was studied. The result obtained is discussed for the Reynolds number ranging from 8000 and 17000.

The result of this study is presented in term of Nusselt number and friction factor ratio as function of influencing parameter of ring sector. The Nusselt number ratio based on equal Reynolds number is represented as \( Nu/Nus \). \( Nu \) is experimental value of Nusselt number in presence of ring sector. \( Nus \) is the Nusselt number values for smooth tube on the basis of equal Reynolds number.

The friction factor ratio based on equal Reynolds number is represented as ‘\( f/fs \)’. The friction factor corresponding to rough tube with ring sector is \( f \). Similarly the friction factor corresponding to smooth tube without ring sector is \( fs \).

Fig. 5 & 6 shows variation of \( Nu/Nus \), \( f/fs \) respectively for \( P/D=3 \). Fig. 7 & 8 shows variation of \( Nu/Nus \), \( f/fs \) respectively for \( P/D=4 \). Fig. 10 & 11 shows variation of \( Nu/Nus \), \( f/fs \) respectively for \( P/D=6 \).
IV. CONCLUSION

It is observed that as axial pitch of ring sector goes on increasing, Nusselt number ratio and friction factor ratio goes on decreasing. The ring structure down stream of ring sector promotes mixing of the wall and core fluid. The mixing of fluid weaker as the distance from the ring sector increases. Nu/Nus increase with decrease in P/D ratio. Increased fluid mixing leads to higher heat transfer coefficient and also increased pressure drop values. This complex interaction result in a peak at P/D= 4.

Next a fixed Reynolds number was taken and angle of attack is varied. As angle of attack decrease from 90° to 15°, Nusselt number decreases and friction factor ratio decreases. With increasing values of angle of attack, Nu/Nus and f/fs increase. The Nu/Nus values shows small increase with increase in angle of attack. The larger angle of attack imply longer zone of mixing between the core and the wall fluid, enhancing the heat transfer coefficient. The cross stream mixing also induces larger pressure drop. The projection of ring sector is necessary to attach the ring sectors with the central rod. This protrusion adds to the resistance to the flow thus increasing f/fs values. On other hand this increases fluid mixing and facilitate increase in heat transfer. The best results were obtained for optimum values of angle of attack = 45 and axial pitch to diameter ratio (P/D) = 4.

REFERENCES


