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Numerical Investigation of Convective Heat Transfer and Pressure Loss in a Round tube Fitted with Circular-Ring Turbulators

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Abstract- Computational heat transfer flow modeling is one of the great challenges in the classical sciences. As with most problems in engineering, the interest in the heat transfer augmentation is increasing due to its extreme importance in various industrial applications. CFD modeling for the heat transfer augmentation in a circular tube fitted with and without rod circular inserts in turbulent flow conditions has been explained in this paper using ANSYS Fluent version 14.0. This paper presents the effect of the circular-ring turbulator (CRT) on the heat transfer and fluid friction characteristics in a heat exchanger tube. The experiments were conducted by insertion of CRTs with various geometries, including three different diameter ratios (DR=d/D=0.5, 0.6 and 0.7) and two different pitch ratios (PR=p/D=4, 8). During the CFD simulation air at 27 °C was passed through the test tube which was controlled under uniform wall heat flux condition. The Reynolds number was varied from 4000 to 20,000. According to the experimental results, heat transfer rates in the tube fitted with CRTs are augmented around 57% to 195% compared to that in the plain tube, depending upon operating conditions. In addition, the results also reveal the CRT with the smallest pitch and diameter ratios offers the highest heat transfer rate in accompany with the largest pressure loss.

Index Terms- CFD, CRT,Diameter Ratio, Pitch Ratio

I. INTRODUCTION

The heat transfer augmentation techniques are widely utilized in many applications in the heating process to enable reduction in weight and size or increase the performance of heat exchangers. These techniques are classified as active and passive techniques. The active technique required external power such as surface vibration and electric or acoustic fields, whereas the passive techniques required fluid additives, special surface geometries, or swirl/vortex flow devices, that is, twisted tape inserts. The passive techniques are advantageous compared with the active techniques because the swirl inserts manufacturing process is simple and can be easily employed in an existing heat exchanger. Moreover the passive techniques can play an important role in the heat transfer augmentation if a proper configuration of the insert is being selected depending on working conditions that have been reported in the literature. Due to advances in computer software, the Computational Fluid Dynamics (CFD) modeling technique was developed as a powerful and effective tool for more understanding the hydrodynamics of heat transfer when using twist tape inserts.

Efficient utilization, conversion and recovery of heat are the predominant engineering problems of the process industry. The subject of enhanced heat transfer has developed to the stage that it is of serious interest for heat exchanger design. There are three different approaches to the enhancement of tube-side convective heat transfer, namely, inserted devices, internal fins and integral roughness. Insert devices involve various geometric forms that are inserted in a smooth, circular tube. Integral internal fins and roughness require deformation of the material on the inside surface of a long tube. The method of preference depends on two factors, the performance and initial cost.

CFD works by splitting a fluid domain (in this case a tube), into small cells creating a mesh. The computer program then solves the heat transfer and transport equations for each of the cell until it converges to a stable answerer. The advantage of using CFD is that the flow patterns inside the tube can be observed without having an effect on the result. (Versteeg and Malalasekera(2007))S.K.SahaA.Dutta,[1]experimentally studied the flow of servotherm oil in acrylic circular tube fitted with insulated stainless steel twisted tape insert.

Zhi-Min Lin, Liang-Bi Wang, [2] in their experimental study of air flow in Plexiglas circular tube used Stain less steel twisted tape insert.

WatcharinNoothong et al. [3] their aim to investigate the efficiency enhancement and to study the heat transfer and friction factor characteristics of heat exchanger. In the experimental study, concentric double tube Plexiglas materialed heat exchanger was used Paisarn Naphon, [4] in his experimental study he used hot and chilled water in horizontal copper double tube heat exchanger fitted with aluminum twisted tape inside. Smith Eiamsa-ard et al., [5] their aim was to analyze heat transfer and flow friction characteristics in a copper tube double pipe counter flow heat exchanger, containing the stainless steel helical screw-tape with or without core-rod inside. Hot and chilled water used for experimentation. Ashis K. Mazumder and Sujoy K. Saha, [6] performs the experimental study in a square and rectangular acrylic ducts fitted with full and short length twisted tape. Yakut et al. [10,11] reported the effect of conical-ring turbulators on the heat transfer, pressure drop, flow-induced vibration and vortices. Promvonge [12] studied the effects of the conical ring turbulator arrangements which were converging conical ring (CR array), diverging conical ring (DR array) and converging-diverging conical ring (CDR array) on the heat transfer rate, friction factor and thermal performance factor.

Durmus [13] investigated the effect of angle arrangement of the conical type turbulators on the heat transfer and friction loss. Their results revealed that heat transfer rate as well as friction coefficient increased with increasing turbulator angle. Recently, Promvonge and Eiamsa-ard [14] combined effect of conical-ring with that of a twisted-tape for heat transfer enhancement in the circular tube. As reported, the use of the conical-ring together with the twisted-tape provided an average heat transfer rate up to 10% over that for using the conical-ring alone.

Apart from experimental investigations, the numerical studies on heat transfer enhancement by means of the circular ring turbulators were also stated [17,18]. Ozceyhan et al. [17] numerically studied effect of space between the circular cross sectional rings on heat transfer rate and friction factor. Similarly, Akansu [18] numerically investigated effect of space between porous rings. The obtained result from both works demonstrated that heat transfer rate and friction factor increase with decreasing ring spacing. Pongjet Promvonge .et.al [20] analysed Effects of combined ribs and winglet type vortex generators (WVGs) on forced convection heat transfer and friction loss behaviors for turbulent airflow through a constant heat flux channel are experimentally investigated. Siva Kumar. et.al [21] studied the local heat transfer and Nusselt number of developed turbulent flow in convergent/divergent square duct have been investigated computationally.

This paper presents the effect of the circular-ring turbulator (CRT) on the heat transfer and fluid friction characteristics in a heat exchanger tube. The experiments were conducted by insertion of CRTs with various geometries, including three different diameter ratios (DR=d/D=0.5, 0.6 and 0.7) and two different pitch ratios (PR=p/D=4, 8). During the test air at 27 °C was passed through the test tube which was controlled under uniform wall heat flux condition. The Reynolds number was varied from 4000 to 20,000.

II. CFD Modelling of Smooth and Circular Ring Turbulators

The details of the tube with circular-ring turbulators or CRTs are demonstrated in Fig.1. The circular-ring turbulators are made of aluminum with 5 mm thickness. The outer diameter of the turbulators(D) was fixed at 62 mm while inner diameters were varied at 31 mm(0.5D), 37.2 mm (0.6D), and 43.4 mm (0.7D). In the experiments, the CRTs were installed in the test tube using small wire to tie elements with different pitch lengths; p=248 mm (PR=p/D=6), 496mm (PR=8), and 744 mm (PR=12), to generate different turbulence intensities. The test section is made of copper tube with 63mm in inner diameter, 1500 mm in length (L) and 2mm in thick (t).

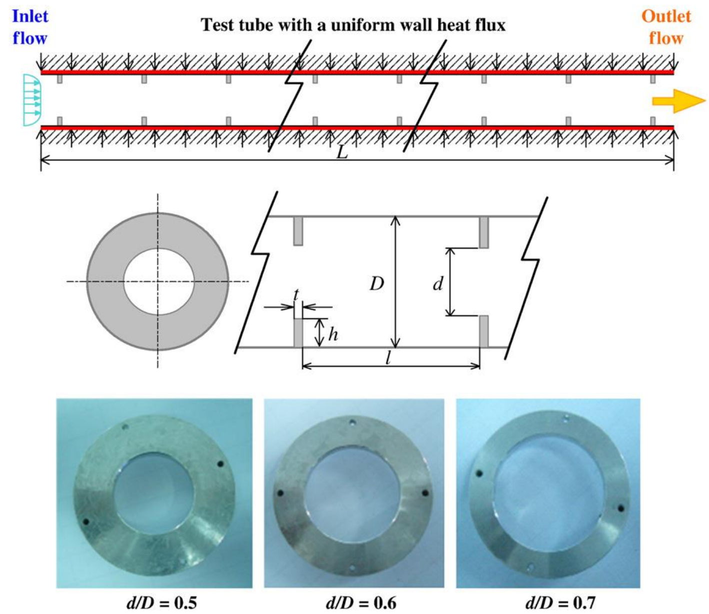

Fig.1 Geometry under investigation: Test section with circular-ring turbulators (CRT).

III. CFD Meshing

The whole computational domain has to be divided into small control volumes, called grid cells in order to solve the discretized transport equations. Constructing a computational grid is a constant tradeoff between accuracy and CPU-time; when a grid is coarse the systems that have to be solved are small which implies short-CPU times. The downside is that a coarse grid is unable to represent small velocity or pressure gradients in the flow field. A very fine grid will be more accurate but can take undesirably long CPU-times. An additional disadvantage of a fine grid is that discretization gives a small round off error for every grid cell; more grid cells imply more round off errors

The computational grid used in this thesis can be found in Fig.2 to 6 . The grid is created with the program “AMP”. This is a standard mesh-generator compatible with several CFD packages, including Fluent. The main advantages of this program are the automatic mesh generator and the extended options to adapt the model to user preferences. AMP defines the model, grid and all boundary types.

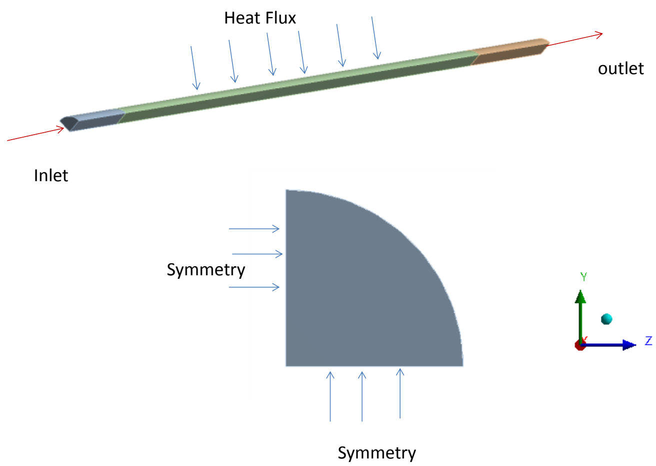

Fig. 2.CFD Domain of smooth tube heat exchanger

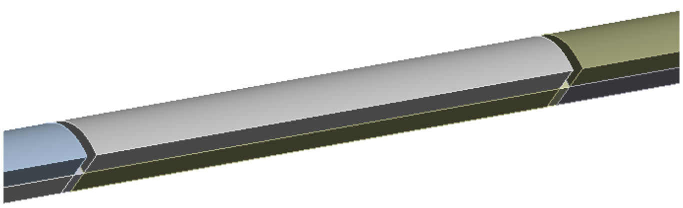

Fig.3.CFD Model of Circular turbulator

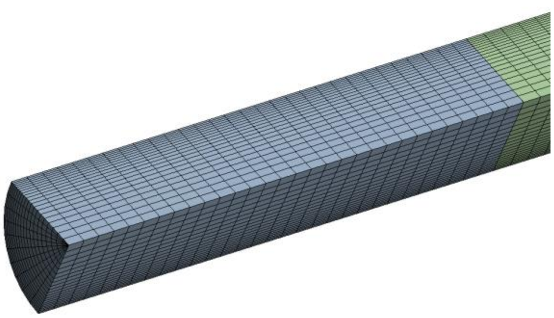

Fig.4. CFD Meshing Smooth Tube Zoomed view

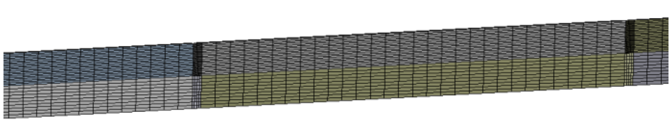

Fig.5. CFD Meshing of Circular turbulator

IV. RESULTS AND DISCUSSIONS

A.Smooth Tube

Fig.6 shows the Pressure contours smooth tube velocity 0.94m/s. In these contours shows smooth tube pressure drop 0.68Pa.

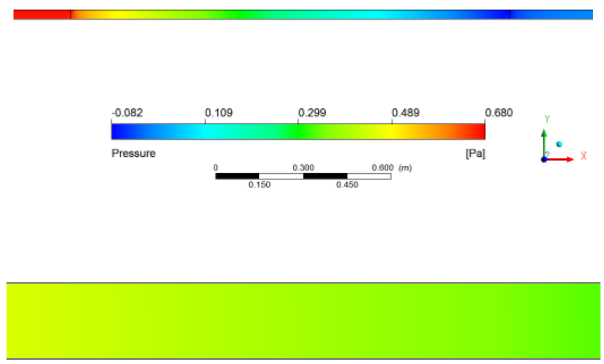

Fig.6.Pressure contours smooth tube velocity Re=4000

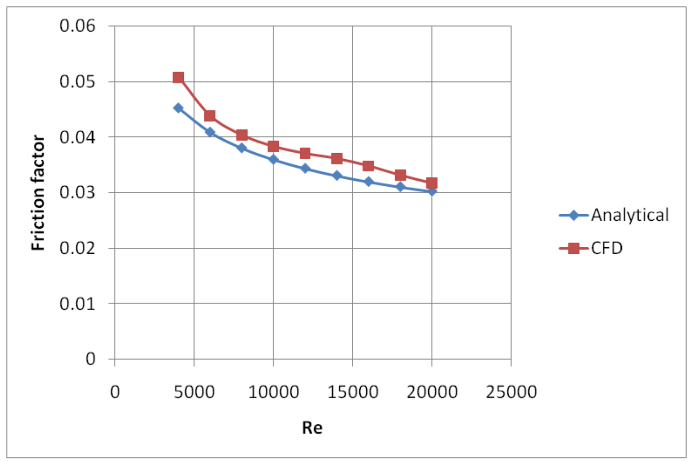

Fig.7 Comparisons of CFD and experimental data and empirical correlations of the plain tube for Friction factor

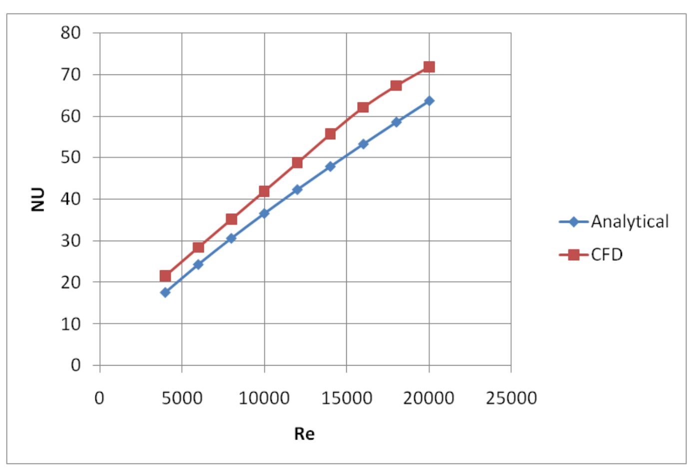

Fig.8. Comparisons of CFD and experimental data and empirical correlations of the plain tube for Nu

Fig 7 and 8 shows comparison between the present experimental and analytical work. In the figures, the present work agrees well with the available correlations with ±10% in comparison Dittus–Boelter for the friction factor.

B.Circular-ring turbulators PR=4 and d/D=0.5

Fig.9 shows the Pressure contours for conical turbulator PR=4, d/D=0.5 and Re=4000. It shows the pressure drop of 71 Pa which is increased compared to smooth tube due to friction loss of the tube and groove or roughness of the tube.

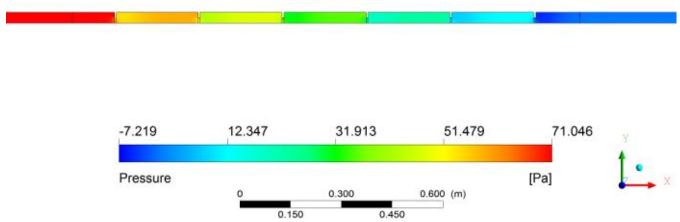

Fig.9 Pressure contours conical turbulator PR=4, d/D=0.5 and Re=4000

Fig.10 shows Velocity contours conical turbulator Re=4000.Also shows the Velocity vectors. The conical turbulator causes more turbulence intensity in the flow, because its sharp corner edge can produce more turbulence than the smooth surface, but, it causes more recirculation region inside the groove. So, it prevents good mixing of the fluid. Thus, it results in increase of heat transfer compare with plain tubes.

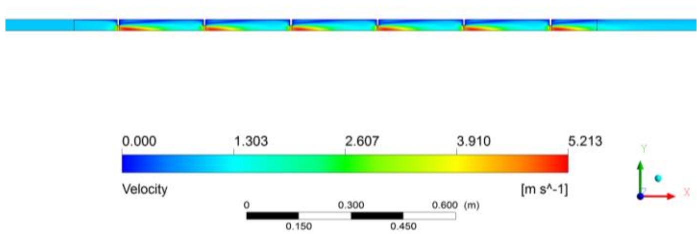

Fig.10 Velocity contours conical turbulator PR=4, d/D=0.5 and Re=4000

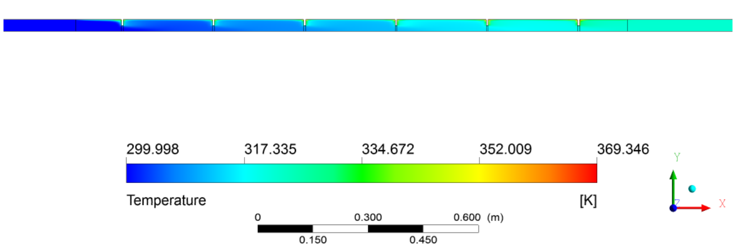

Fig.11 Temperature contours conical turbulator PR=4, d/D=0.5 and Re=4000

Fig.11 shows the Temperature contours conical turbulators PR=4, d/D=0.5 and Re=4000. It shows the higher temperature of 369.3 K at solid wall also it shows temperature rise from inlet to outlet due to heat exchange between from the outer wall to fluid water. The effect of recirculation and vortices formed in the cavities on the temperature contours that causes heat transfer enhancement is clearly observed in this figure11.

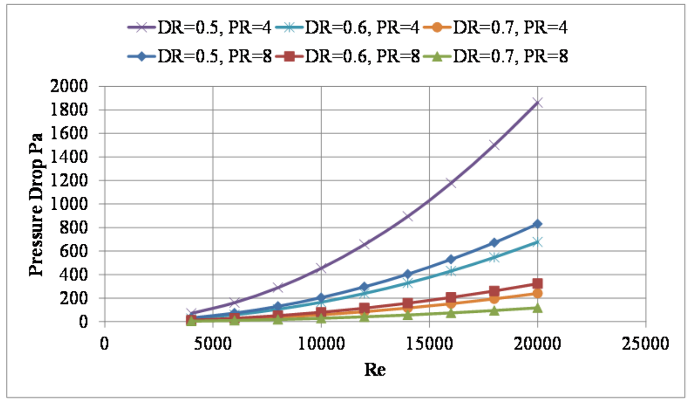

Fig.12 Pressure drop Pa Vs Reynolds Number

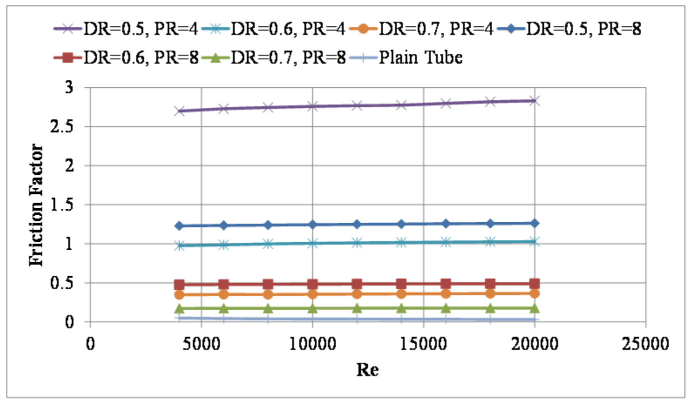

Fig.13 Friction Factor Vs Reynolds Number

Influence of the CRTs with different diameter ratios (DR=0.5, 0.6 and 0.7) on the friction factor is presented in Fig.14. Obviously, friction factor tends to decrease with increasing Reynolds number for all CRTs. It is also visible that the use of CRT leads to a substantial increase in friction factor over that in the plain tube. One can observe from the figure that at the given Reynolds number, friction factor increases with the decrease of the diameter ratio. Since at a smaller diameter ratio, a greater flow interruption and thus inertial forces in the boundary layer becomes. The friction factor increases cause by the CRTs with the diameter ratio, DR=0.5, 0.6 and 0.7 are respectively found to be 48, 20 and 8.5 times of those in the plain tube.

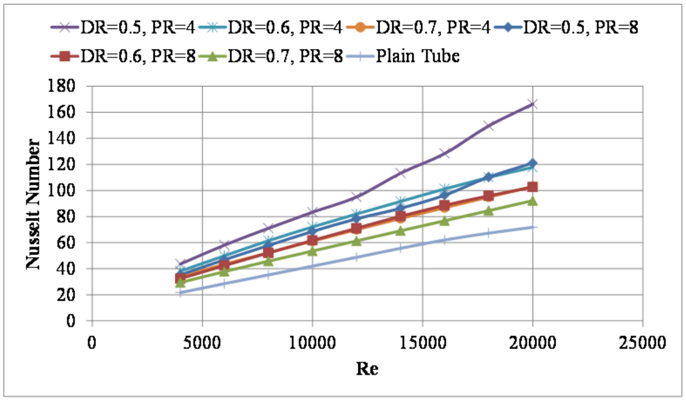

Fig.13 Nu Vs Reynolds Number

Influence of using the CRT with different diameter ratios (DR=0.5, 0.6 and 0.7) in turbulent tube flow on heat transfer enhancement behavior is demonstrated in Fig. 13. At the given Reynolds number, Nusselt number (heat transfer rate) in the tube equipped with CRT is higher than that in the plain tube, for the whole range investigated. Depending upon the operating condition, CRTs enhance heat transfer rate from 1.6 to 2.9 times of those in the plain tube. This is a result of thermal boundary destruction by the CRTs. In addition, heat transfer enhancement is amplified at high Reynolds numbers since the convective heat transfer is promoted more effectively at a higher turbulence level. The numerical results also reveal that the CRT with a smaller diameter ratio generates more efficient flow blockage, giving stronger turbulence intensity and thus a superior heat transfer rate than the CRT with a larger diameter ratio. The corresponding increases in the mean heat transfer rates in the turbulent tube flow fitted with CRT with respect to those of the plain tube are about 136%, 111 % and 93%, for DR=0.5, 0.6 and 0.7, respectively. For comparative results, the CRT with DR=0.5, augment heat transfer rate 5.9–15.3% and 8.5–32% over the CRTswith diameter ratios, DR=0.6 and DR=0.7, respectively.

V. CONCLUSION

Insertion of turbulators in the flow passage is one of the favorable passive heat transfer augmentation techniques due to their advantages of easy fabrication, operation as well as low maintenance. In general, the performance of turbulators strongly depends on their geometries. In earlier investigations, turbulators with several shapes were utilized to promote heat transfer.

Heat transfer enhancement in a tube fitted with circular-ring turbulator (CRT) is reported in this thesis simulated using ANSYS Fluent CFD software. Computational heat transfer flow modeling is one of the great challenges in the classical sciences. As with most problems in engineering, the interest in the heat transfer augmentation is increasing due to its extreme importance in various industrial applications. Influence of the diameter ratio (DR) and pitch ratio (PR) on the heat transfer rate, friction factor and thermal performance factor behaviors was investigated under uniform wall heat flux condition. The CRTs with different diameter ratios (DR=d/D=0.5, 0.6 and 0.7) and pitch ratios (4 and 8) were employed for the Reynolds number ranged between 4000 and 20,000. Over the entire range investigated CRTs propose heat transfer enhancement around 57% to 195% compared to that in the plain tube.

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