Southeast-Asian J. of Sciences Vol. 5, No. 2 (2017) pp. 126-136

ENHANCEMENT OF HEAT TRANSFER IN A U-LOOP CIRCULAR TUBE WITH AXIAL PERFORATED INSERTS

Simul Acherjee [1], **M.Shahriar** [2],
M.M. Bhuyan [3] and **Ujjwal Kumar Deb** [4*]

[1] *Department of Mathematics*
Narangiri Govt. High School
Rangamati-4531, Bangladesh
email: acherjeesimul@gmail.com

[2] *Department of Mechanical Engineering*
Chittagong University of Engineering & Tecnology
Chittagong-4349, Bangladesh
email:tanim0907@gmail.com

[3] *Department of Electrical & Electronics Engineering*
Southern University Bangladesh
Chittagong-4000, Bangladesh
email:mmbhuyan87@southern.edu.bd

[4] *Department of Mathematics*
Chittagong University of Engineering & Tecnology
Chittagong-4349, Bangladesh
email:ukdeb03@gmail.com

Abstract

In practical applications inserts of various geometrical shapes we used to enhance the heat transfer. So many experiments have been carried out for a circular tube using various types of inserts. In our investigation, we have used perforated axial inserts in the straight part of U-loop circular pipe. The non-isothermal laminar flow is considered as the physics for fluid flow inside the tube. A copper pipe with 3435.62mm long, 70mm diameter and 5mm thickness is taken for our simulation. Two 1600mmx70mmx2mm rectangular copper plates with perforated are used as inserts inside the tube fitted in perpendicular to the fluid flow. For our simulation, we have used a uniform heat-flux around the

Key words: heat transfer, perforated inserts, u-loop pipe, laminar flow, simulation.

U-loop circular tube. The variations of temperature and pressure drops are examined for with inserts and without insert. Finally we compare the results for a without perforated insert tube. We found a significant difference between both results where the perforated inserts enhanced the amount of heat transfer than the without perforated inserts for a fluid flow.

1 Introduction

The exchange of heat depends on many things, such as types of fluid, inserts, kinds of metal, characteristics of fluid flow etc. Nowadays, its a challenge for every researcher to transfer the maximum amount of heat with the minimum cost. In this regard researchers use various techniques for the enhancement of heat transfer with the special surface geometry.

In the early 20th century this topics came forward to the researcher and later the heat transfer techniques have been developed day by day. Many kinds of inserts have been used to increase the exchange of heat. An experimental investigation was carried out for Delta-Winglet Twisted tape [DWT] inserts by S. Eimasa-ard et al. [1]. In this research they observed that the O-DWT is more efficient then the S-DWT inserts. The increasing of Reynolds number increased the heat transfer enhancement efficiency and the effect of Nusselt number were investigated by Bodius Salam et al. fitted with rectangular cut twisted tape inserts in a tube for turbulent flow [2].

In 2014, Suvanjan et al carried a CFD analysis for full length twisted tape inserts with low Reynolds number laminar flow and studied the heat transfer and flow behavior of different geometric parameters [3]. A simulation type investigation was run by Sabbir Hossan et al. with rectangular box tape inserts where they indicate that distance among the inserts varies the heat transfer rate [4]. Sadashiv and Madhukeshwara.N performed a numerical simulation for the rod helical tape swirl generators [5]. A CFD analysis of various types of V-cut twisted inserts for laminar flow was studied by Sami D. Salman et al. and they found that the highest heat transfer rate generated with the V-cut twisted tape $y = 2.93cm$ and $w = 0.5cm$ then the other V-cut and general twisted tape inserts [6].

Ta-Sung Huang et al. investigated for the flat plane inserts with holes and different angle twisted tape inserts [7]. For triangular wave tape insert A.G. Matani and Md. Rafik S.Choudhari observed that the TWT-D3 designed inserts show better Nusselt number, the friction factor and the heat transfer coefficient than that of design the TWT-D1 and the TWT-D2 [8]. In a review of the performance of different geometries on heat transfer, Amol P. Yadav et al.

suggested for perforated twisted tapes inserts of porosity 4.5% enhanced more heat than the other porosities of 1.6%,8.9% and 14.7% [9]. M. K. Roslim et al. reported for porous twisted plate insert that 3 holes twisted plate obtained highest Nusselt number [10]. In an investigation of Zigzag-Winglet perforated insert fitted tube S. Suwannapan et al. pointed out that the blockage ratio and the Reynolds number are proportional to Nusselt number and friction factor but reciprocal with pitch ratio [11]. For the perforated twisted tape insert J. U. Ahamed et al. identified that the porosity of 4.6% gives the highest value of heat transfer effectiveness [12, 13]. A perforated disc-baffles annulus was performed by A. R. El-Shamy and indicated the highest Nusselt number and friction factor for open area ratio of 18% and S/De = 2 with Reynolds number 48,024 [14]. Md. Mizanuzzaman et al. studied for X-shaped longitudinal perforated inserts and remarked that the porosity of 15.85% occurred higher effectiveness [15]. For the perforated strip inserts and the perforated twisted inserts M. M. K. Bhuiya et al. observed supreme heat transfer coefficient with the porosity of 4.4% and 4.5% respectively[16, 17].

There are two types of investigation are carried by the researcher. One is the experimental type and other is the simulation type investigation.The simulation type investigation gives us more facilities to make model of different geometric combinations to predict the results accurately. It is also noted that in simulation techniques model can be changed easily if any error occurred which saves more time and cost than experimental approach. For this flexibility of investigation it becomes popular to the researchers. For our study, we have used Computational Fluid Dynamics (CFD) simulation techniques to solve the flow phenomena coupled with heat transfer.

From the above literature, we have observed that no research being held with U-loop circular tube with axial perforated inserts. So we assume that this type of inserts get a good result to transform the heat. Water has taken as a working fluid and the non-isothermal laminar flow physics has been considered for our simulation. In general, fluid with laminar flow enhanced more heat. If inserts are added the heat transfer rate becomes higher. The perforated inserts help the fluid particle to make swirly and stay more time inside the tube which increase the heat transfer rate.

The goal of this research is to study the heat transfer rate and fluid flow behavior in a tube with axial perforated inserts. We also compare the results for heat transfer with without perforated inserts tube and plane tube from our simulation.Finally we will compare the results with those previous exerimental results.

2 Governing equations

In our study ,a model of heat transfer augmentation in a U-loop tube with axial perforated inserts is developed to solve the heat transfer phenomena. Some simplifications are needed for the application of convectional flow equation and energy equation. Hence the governing equation for the enhancement of heat transfer phenomena in our simulation is arranged by the equations are as follows [18]:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \mathbf{u}) = 0. \tag{1}$$

The continuity equation of the fluid flow represents by equation (1), which describes the rate of change of density in the fluid at a fixed point.The rate of change of momentum at per unit volume of the fluid describes by equation (2).

$$\rho\frac{\partial \mathbf{u}}{\partial t} = \nabla.[-P\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - 2/3\mu(\nabla.\mathbf{u})\mathbf{I}] + \mathbf{F} \tag{2}$$

The convective acceleration of the fluid particle is presented by the left hand side of this equation. The pressure gradient is stated by the first term of the right hand side and while the next two terms represents the viscosity and its relation with the temperature. The viscosity is used as a diffusion of momentum. Any other forces such as: gravity force are defined by the last term of the equation.

$$\rho C_p\frac{\partial \mathbf{T}}{\partial t} + \rho C_p\mathbf{u}.\nabla\mathbf{T} = \nabla.(k\nabla\mathbf{T}) + Q + Q_{vh} + W_P \tag{3}$$

The equation (3) represents the heat transfer in a fluid for the time-dependent condition, where the left-hand side states heat transfer via convection and the first term of the right hand side is the basis of Fouriers law which describes conduction. The viscous heating contribution is presented by Q_{vh}, which implies the heating from the fraction of the fluid on the wall of the inner portion of the tube.W_p represents the work done by pressure. The relation with the inertial force and the viscocityis given by the relation (4) as follows:

$$R_e = \frac{\rho\mathbf{u}D}{\mu} \tag{4}$$

where, R_e is the reynolds number of the flowing fluid, D is the inside diameter of the tube and u is the velocity of the fluid. The ranges of Reynolds number describe the character of the fluid flow. For an insufficient inertia forces relative to viscous forces the Reynolds number becomes small and the flow remains laminar with the range of less than 2300.

The porosity of the insert is expressed by:

$$R_p = \frac{\frac{\pi}{4}d^2}{L*W} \tag{5}$$

Where L is the length, W is the width of the tape and d is the diameter of the pore.

3 Boundary conditions

The boundary conditions for the fluid flow are considered as follows: $\mathbf{u} = 0$ defined no slip condition for the wall. The inlet velocity in the velocity field is$u = u_0$ from $0.014ms^{-1}$ to $0.029ms^{-1}$ with an initial temperature $T = T_0 = 293.15K$ and for the outlet of domain zero normal stress is considered and the equation is given below :

$$[-pI + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T - 2/3\mu(\nabla\mathbf{u})I)].\mathbf{n} = -f_o\mathbf{n} \quad (6)$$

4 Computational Domain and Meshes

A 3435.62 mm long circular copper pipe with 70 mm inner diameter and 5 mm thickness is taken as the comtational domain for our simulation shown in Fig 4.1. Water is chosen as the working fluid. In Fig 4.2 the perforated rectangular copper inserts are used inside the pipe perpendicular with the fluid flow.The dimension of the inserts are $1600mm$ long,$70mm$ in width and $2mm$ in breadth.

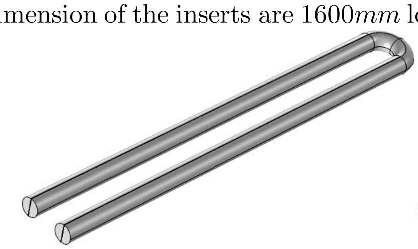


Fig. 4.1: The computational domain.

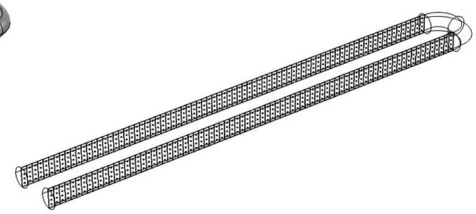


Fig. 4.2:The domain with inserts.

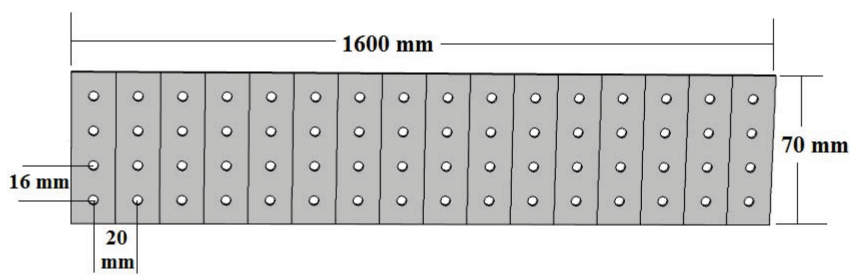


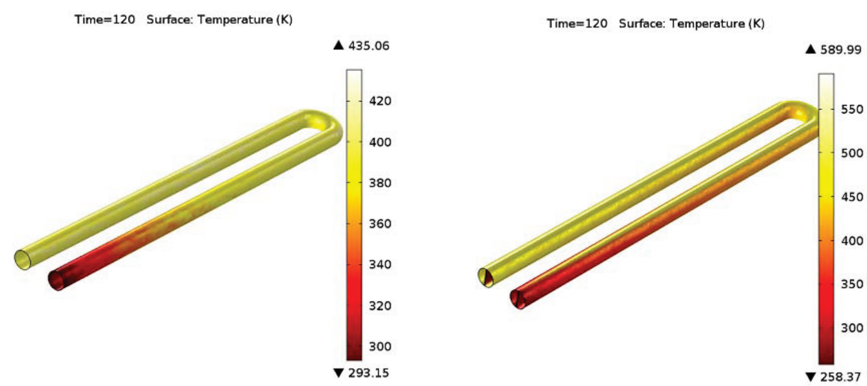
Fig. 4.3: Dimension of insert and pores.

The inserts and the pores dimension are highlighted in Fig 4.3, where the axial distance between two adjacent holes is 20 mm and transverse wise is 16 mm. Five different types of perforated insert is taken for the test session in the similar manner. The inserts porosities are $R_p = 4.42$, 4.5, 4.6, 15.83 and 50% with analogous pore diameters of 4.44, 4.48, 4.34, 8.4 and 15 mm respectively.

To compute the results with accuracy, we need smooth meshing for the domain. In this regards we used finer mesh for all domain. Since our domain is large, so we need a powerful computer to compute the results. For the computing we used intel core i7 processor with 16GB DDR3 RAM based computer.Here we observed that the mesh element clustered around the inserts.

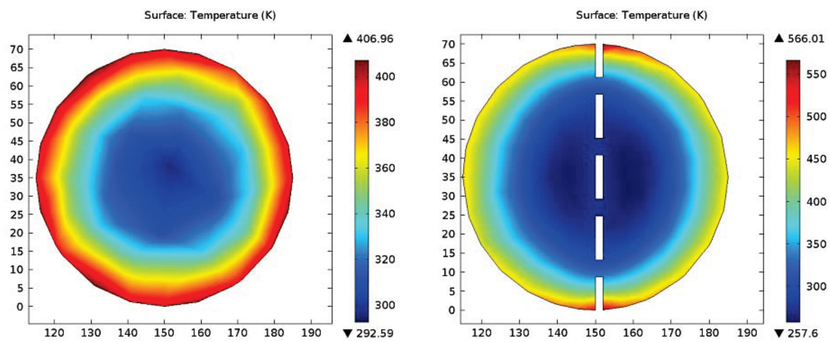
5 Results and Discussion

In this paper, we investigate the heat transfer phenomena for the tube fitted with axial perforated inserts from the simulated results. For this simulation we used five deferent porosities of 4.42%, 4.50%, 4.62% 15.83% and 50.00% with the pore diameter of 4.44, 4.48, 4.34, 8.4 and 15 mm respectively around the Reynolds number of 1100 to 2300. The simulated results for the water are measured through a copper tube with inserts and without insert. The depth of the tube is ignored and a constant heat flux is considered for the tube neighboring to the surfaces of the water domain. An extremely conductive layer with a constant heat flux of $32087 w/m^2$ is generated along the boundary. As our goal is to analyze the heat transfer rate so the convection of heat through the solid is neglected. We used COMSOL Multiphysics of version 4.2a to carry out our simulation.



(a) Plain tube (b) $R_p = 4.42\%$

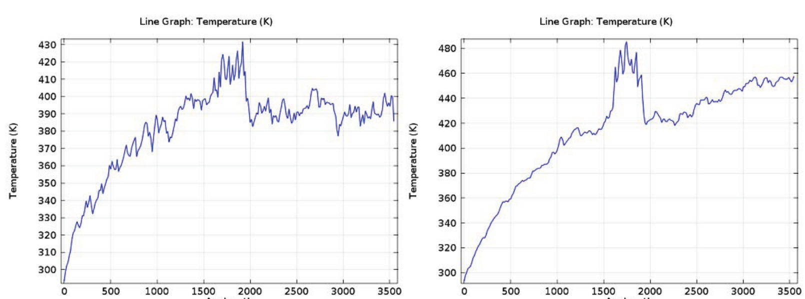
Fig. 5.1: Surface temperature of the fluid



(a) Plain tube (b) $R_p = 4.42\%$

Fig. 5.2: Cross sectional view of temperature distribution.

Fig. 5.1(a, b) shows that tube with inserts enhance the heat transfer rate than the plain tube. Fig. 5.2(a, b) represents the cross sectional view of the domain taken $10mm$ from the outlet. In those figures we observed that in case of the plain tube temperatures are increased about 435.06 k and 406.96 k while the tube with 4.42% porosities of perforated inserts enhanced the temperatures about 589.99 k and 566.01 k respectively at the Reynolds number 2300, this is because the fluid particle in a plain tube move rapidly without any obstacle so the streamlines for the fluid particles are as the straight lines. In this case, the fluid particle near the surface only takes heat from the wall but it does not get more time to supply it in the central fluid particle. On the other hand if inserts is used than the fluid particle makes swirly and takes more time for this obstacle than the streamline for a fluid particle becomes a curve which increase the friction among the fluid particle and thus the temperature being raised



(a) Plain tube (b) $R_p = 4.42\%$

Fig. 5.3: Temperature line graph of the fluid for the (a) plane tube and (b) 4.42% perforated inserts tube

TABLE 5.3:The temperature of the fluid in plane tube and tube with different types of porosities.(For Reynolds number 2300)

Plaintube	385.67K
Without perforated insert tube	437.19K
Porosity,R_p,4.42%	457.66K
Porosity,R_p,4.50%	454.45K
Porosity,R_p,4.62%	451.07K
Porosity,R_p,15.83%	449.13K
Porosity,R_p,50%	454.60K

The Fig 5.3(a, b) represents the fluid temperature for the plane tube and the tube with 4.42% porosities respectively. We observed that the temperature rises with a upward trend for the first straight part of the tube, after that a sudden peak occurs at the U-loop section which indicates the direction of fluid particle rapid change and makes more swirly than the any other part of the tube. After passing the U-loop a sharp downward shows the fluid entered into the another straight part of the pipe, after there is a rough fluctuation for the plane tube in Fig 5.3(a, b) and an upward trend for all the tube with the different porosities which express the increasing of temperature. The fluid temperature is higher for the tube with inserts than the plane tube as the swirly generator of fluid with the inserts. In Table 5.3 we observed that the porosity of 4.42% enhanced more temperature than any other porosities and a significant amount of heat exchange than the plane tube and tube without perforated inserts at the Reynolds number 2300.

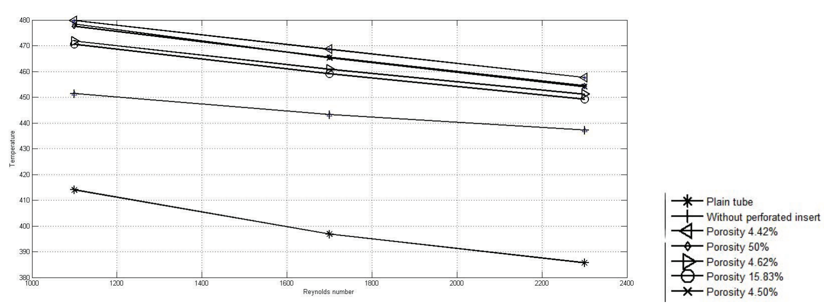
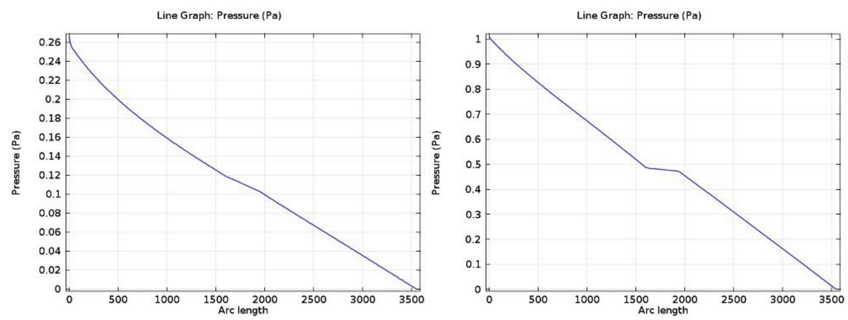


Fig. 5.4: Variation of temperature with Reynolds number for the different porosities.

The correlation between the fluid temperature and the Reynolds number is shown in Fig. 5.4 for the different types of porosities and plain tube. Fig 5.4 publicized if the Reynolds number is higher than the fluid temperature being low for all porosities of the inserts. This is because the increasing of Reynolds number led the fluid more turbulence but gives less time to stay inside the tube with the increasing velocity. According to our assumption from Fig 5.4, the fluid temperature for all the axial perforated inserts tube for all Reynolds number is notably higher than the plain tube which indicates the swirly generated inserts helps to mix the fluid of the wall region with the fluid from the core region. This graph also indicates that the porosity of 4.42% enhanced more heat among the porosities for all Reynolds numbers and it exchanges a remarkable amount of heat than the plane tube. In addition, this result is shown better agreement with previous experimental work [16].



(a) Plain tube (b) $R_p = 4.50\%$

Fig 5.5: pressure drop at (a)the plain tube and (b) the tube with Rp =4.50% A regular pressure drop is found in Fig. 5.5 (a) for the plain tube from the inlet to the outlet. In Fig. 5.5 (b) it is noted that a downward trend of pressure drop is found for the first straight part of the domain, after that it remains constant for the U-loop portion and then it gradually downward which indicates the fluid particle takes enough time to complete the path and enhanced more heat than plain tube.

6 Conclusion

A simulation based investigation carried with the perforated inserts tube and plain tube to investigate the heat transfer characteristics and pressure drop. In this investigation we identified that the tube with inserts enhanced a remarkable heat than of plain tube without any external effect and a notable pressure drop found for the tube with inserts which influince the fluid particle to exchange a huge amount of heat than plain tube. In our observation we marked that the heat transfer rate is decreased at all porosities and the plain tube with the increasing of the Reynolds number We also note that the porosity of 4.42% for the tube enhanced maximum amount of heat at all Reynolds number for the laminer flow.

Acknowledgment The authors gratefully acknowledge for the technical supports provided by the Centre of Excellence in Mathematics, Department of Mathematics, Mahidol University, Bangkok 10400, Thailand.

References

[1] S. Eiamsa-ard, K. Wongcharee, P. Eiamsa-ard, and C. Thianpong, *Heat transfer enhancement in a tube using delta-winglet twisted tape inserts,* Applied Thermal Engineering, vol. 30, no.4, (2010) pp. 310-318.

[2] Bodius Salam, , Sumana Biswas,Shuvra Saha,Muhammad Mostafa K. Bhuiya, *Heat Transfer Enhancement in a Tube using Rectangular-cut Twisted Tape Insert,* 5th BSME International Conference on Thermal Engineering, Procedia Engineering, Volume 56, (2013) pp. 96-103.

[3] Suvanjan Bhattacharyya, Tamal Roy, Niladri Ghosh, Satyaki Bandyopadhyay, Sudipta Sarkar, Partha Panja, *Convective heat transfer enhancement in low reynolds number of a circular pipe with full length twisted tape insert,* Proceedings of 12th IRF International Conference, 29th June-2014, Pune, India

[4] Sabbir Hossain, Ujjwal Kumar Deb, Kazi Afzalur Rahman, *The Enhancement of Heat Transfer in a Circular Tube with Insert and without Insert by Using the Finite Element Method,* The 6th BSME International Conference on Thermal Engineering, Procedia Engineering, Volume 105, (2015) pp. 81-88.

[5] Sadashiv, N. Madhukeshwara, *Numerical Simulation of Enhancement of Heat Transfer in a Tube with And without Rod Helical tape Swirl Generators,* International journal of research in aeronautical and mechanical engineering, Vol 2, Issue 1, January 2014, pp. 112-128.

[6] Sami D. Salman, Abdul Amir H. Kadhum, Mohd S. Takriff, and Abu BakarMohamad, *Numerical Investigation of Heat Transfer and Friction Factor Characteristics in a Circular Tube Fitted with V-Cut Twisted Tape Inserts,* Hindawi Publishing Corporation, The Scientific World Journal Volume 2013, Article ID 492762.

[7] Ta-Sung Huang, Pai-Hsiang Wang, Yu-Wei Chiu and Jiin-yuh Jang, *Heat And Fluid Flow Analysis Over Different Tube Inserts Of Recuperator,* China Steel Technical Report, No. 21,(2008) pp. 67-76.

[8] A.G. Matani, Md.Rafik S. Choudhari, *Analysis of Heat Transfer Augmentation in Tube Using Triangular Wavy Tape Inserts,* International Journal of Engineering Research and General Science Volume 3, Issue 3, May-June, 2015.

[9] Amol P. Yadav, Pranit M. Patil, Dr. P. A. Patil, *The Effect of insertion of different geometries on heat transfer performance in circular pipe,* A review, International J. of Modern Engineering Research (IJMER), Vol. 4 , Iss.11, Nov. 2014, pp. 47-53.

[10] Muhammad Khairi Roslim, Suhaimi Hassan and Aklilu Tesfamichael, *Experimental Investigation on Heat Transfer Enhancement by Using Porous Twisted Plate as an Insert in a Fitted Tube,* ARPN J. of Engineering and Applied Sciences, Vol. 10, No 21, November, 2015.

[11] S. Suwannapan, S. Skullong , P. Promvonge, *Thermal Characteristics in a Heat Exchanger Tube Fitted with Zigzagwinglet Perforated Tapes,* Journal of Research and Applications in Mechanical Engineering, Transactions of the TSME (2015) Vol. 3, No. 1, 29 -36

[12] J. U. Ahamed, M. A. Wazed, S. Ahmed, Y. Nukman, T. M. Y. S. Tuan Ya, and M. A. R.Sarkar, *Enhancement and Prediction of Heat Transfer Rate in Turbulent Flow Through Tube with Perforated Twisted Tape Inserts: A New Correlation,* Journal of Heat Transfer, Transactions of the ASME vol. 133, April 2011, pp.041903- 1-9.

[13] J. U. Ahamed, M.A. Wazed, S. Ahmed, M.A.R. Sarkar, *Enhancement of heat transfer in turbulent flow through a tube with a perforated twisted tape insert,* Proceedings of the Inter. Conference on Mechanical Engineering 2007 (ICME2007) 29- 31 December 2007, Dhaka, Bangladesh.

[14] A.R. El-shamy, *Turbulent flow and convective heat transfer in an Annulus with perforated disc-baffles, Eighth International Congress of Fluid Dynamics & Propulsion* (ICFDP 8) December 14-17, 2006, Sharm El-Shiekh, Sinai, Egypt www.zu.edu.eg Paper No.: EG- 185

[15] Md. Mizanuzzaman, Nusrat Jahan, Amina Ahmed Suraia Rahman, Md. Almostasim Mahmud, *Experimental Study of Temperature Distribution in Turbulent Flow through Tubes with Longitudinal Perforated X-Shaped Inserts,* International Journal of Emerging Technology and Advanced Engineering(IJETAE), Volume 3, Issue 1, January 2013, pp. 24-30.

[16] M. M. K. Bhuiya, J. U. Ahamed, M. A. R. Sarkar, B. Salam, H. H. Masjuki, M.A. Kalam, R. Saidur & A. S. M. Sayem (2012): *Heat Transfer and Pressure Drop Characteristics in Turbulent Flow Through a Tube,* Experimental Heat Transfer: A Journal of Thermal Energy Generation, Transport, Storage, and Conversion, 25:4, 301-322

[17] M.M.K. Bhuiya , M.S.U. Chowdhury , M. Saha , M.T. Islam, *Heat transfer and friction factor characteristics in turbulent flow through a tube fitted with perforated twisted tape inserts,* Inter. Comm. in Heat and Mass Transfer, 46 (2013) pp.49-57

[18] www.comsolmltiphysics.com