Study of Heat Transfer Characteristics for the Flow of Air over a Heated Diamond Shaped Tube

Aqib Hussain Mir[1], S. Qadri[2], Yunis Ahmad Dar[3], Kaleem Ahmad Najar[4]

[1,2,3]Department of Mechanical Engineering, National Institute of Technology, Srinagar, J&K, India, 190006
[4]Assistant Professor, Department of Mechanical Engineering, National Institute of Technology, Srinagar, J&K, India, 190006

---***---

Abstract - *The present study considers the steady, incompressible and laminar fluid flow over a heated diamond shaped tube. Flow over tubes is important while designing heat exchangers such as car radiator, cooling towers, electronic component cooling etc. The thermal properties of air were assumed to remain constant. The hydraulic diameter was kept same for diamond and circular shaped tube. The tubes in both cases were subjected to uniform heat flux of 1000 W/m². The governing equations were solved using an academic CFD COMSOL Multiphysics 5.2a software. Heat transfer characteristics were then studied for circular and diamond shaped tubes. The results showed that Nusselt number increased with the increase in Reynolds number for both tube shapes considered in the current study. However Diamond tubes showed higher values of Nusselt number and hence better heat transfer characteristics in comparison to circular shaped tube.*

***Key Words*: Diamond shaped tubes, Hydraulic diameter, CFD, COMSOL Multiphysics, Nusselt number.**

1. INTRODUCTION

The Cross Flow of air over a heated cylinder is frequently encountered in practice. For example, shell-and-tube heat exchanger involve both internal flow through the tubes and external flow over the tubes, and both flows must be considered in the analysis of the heat exchanger [1]. The study is also useful in the thermal analysis of car radiators, cooling towers, electrical and electronic equipment cooling etc. The modern industrial sector requires sensible use of energy. Few studies have shown that tube shape has a significant effect on heat transfer characteristics. It is thus important to determine the tube shape which will increase the heat transfer characteristics so that for a given heat transfer rate, size of the heat transfer equipment is reduced. This is important in applications where available space is a constraint in itself. The present study aims to study heat transfer characteristics of diamond shaped tube and its comparison with conventional circular shaped tube.

1.1 Objectives of the Study

The objectives of the current study are:

1. To study numerically heat transfer from diamond shaped tubes using CFD software COMSOL Multiphysics 5.2a.
2. To compare the heat transfer characteristics such as Nusselt number for both circular and diamond shaped tube.

1.2 LITERATURE REVIEW

Ota et al. [2] studied heat transfer characteristics and flow behaviors have for an elliptic cylinder of axis ratio 1: 3. Reynolds number and angle of attack was varied from 8000 to 79000 and 0° to 90° respectively. It was found that the mean heat transfer coefficient is at its highest at α = 60°–90° over the whole Reynolds number range studied and also that even the lowest value of the mean heat transfer rate is still higher than that for a circular cylinder.

Baughn et al. [3] investigated experimentally heat transfer from a single cylinder, cylinders in tandem, and Cylinders in the entrance region of a tube bank with a uniform heat flux to determine the local heat transfer coefficients around a cylinder. Results were compared to those of other studies with uniform wall heat flux. For the single cylinder, these were found to depend upon blockage, aspect ratio, and free-stream turbulence. For both inline and staggered tube arrangements, the heat transfer coefficient distribution depends on row location but appears to be nearly established by the third row.

Bejan et al. [4] carried out theoretical, numerical and experimental study of finding out the spacing between horizontal cylinders in an array with laminar natural convection. The optimal spacing and maximum heat transfer results predicted theoretically were developed into accurate and well tested correlations by means of numerical simulations and experimental measurements.

2. Methodology

2.1 Geometry and Material properties

3D Geometry of the spherical and circular shaped tubes in a rectangular channel was created using COMSOL Multiphysics 5.2a FEM Software. The hydraulic diameter of the tubes (=13.5 mm) and also the channel dimensions were kept fixed. The hydraulic diameter is a commonly used term when handling flow in tubes of non-circular cross section. It is defined as:

$$D_H = \frac{4A}{P}$$

Where A is the cross-sectional area of the flow and P is the wetted perimeter of the cross-section.

Copper was chosen as a tube material from the inbuilt material library because of its high thermal conductivity. The properties of air however were assumed to be constant.

2.2 Governing equations and Boundary conditions

For steady, incompressible flow of Newtonian fluid, the governing equations are reduced to:

i. Mass conservation:

$$\nabla.\vec{V} = 0$$

ii. Momentum Equation:

$$\vec{V}.(\nabla\vec{V}) = -\nabla P + \upsilon\nabla^2\vec{V}$$

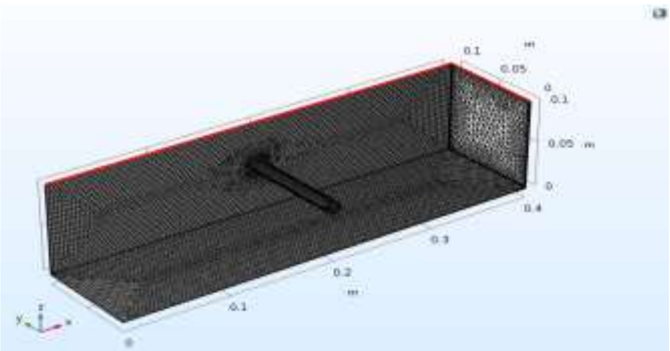
iii. Energy Equation:

$$\rho C_p\vec{V}.(\nabla T) = K\nabla^2 T$$

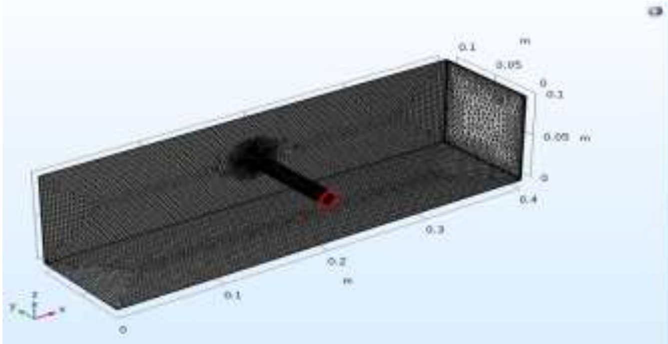
No slip boundary condition was assigned to boundaries where velocity components are set to zero. At the start, the tubes and the channel walls were assumed to be at 293.15 Km2. In all the simulations, the tube surfaces were subjected to uniform heat flux of 1000 W/m^2.

2.3 Meshing

Fine Mesh was selected for the present study to optimize time and accuracy. The elements chosen were of tetrahedral shape with total number of elements for diamond and circular shaped tubes as 665267 and 491599 respectively.



(a)



(b)

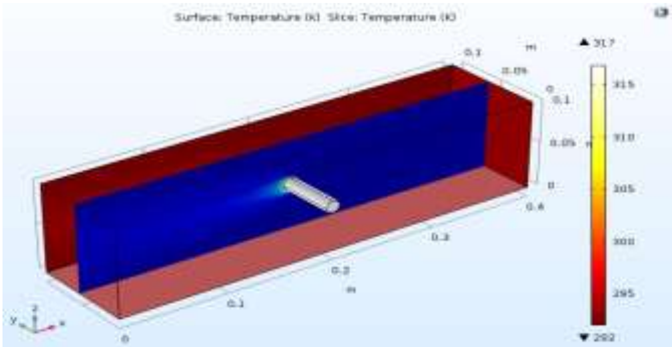
Fig -1: Meshed geometry a) Circular b) Diamond

3. Results and discussion

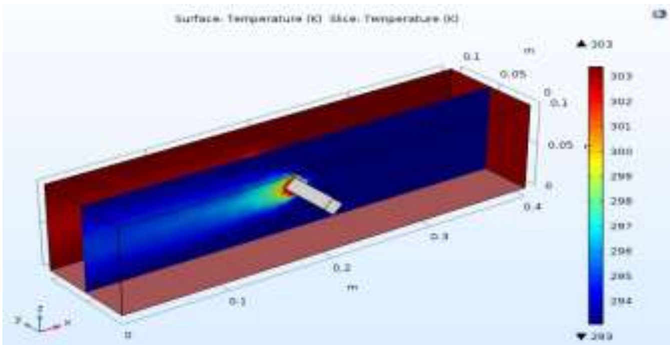
This section shows the simulation results for Temperature distribution, variation of Nusselt number with Reynolds number for spherical and circular tube shape.

3.1 Temperature Distribution

Figure 2 and Figure 3 shows the temperature distribution for circular and diamond shaped tubes for the Reynolds number of 438 and 876 respectively. From the figure, it can be seen that maximum surface temperature was observed for circular shaped tube in comparison to diamond shaped tube. Also at higher Reynolds number, lower surface temperatures were observed.



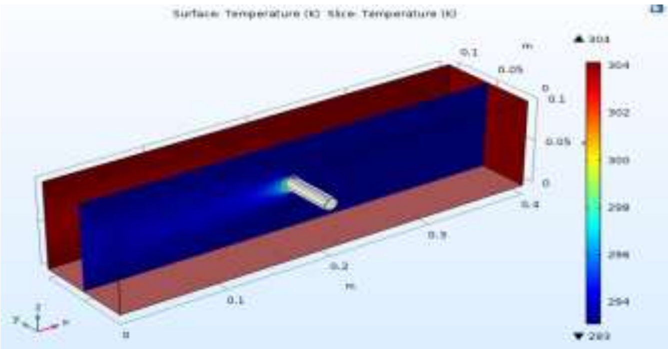
(a)



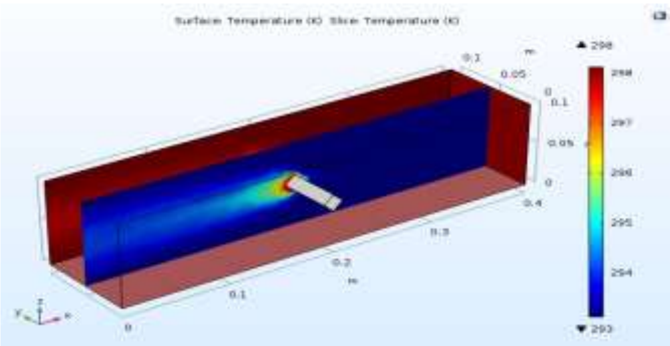
(b)

Fig -2: Temperature distribution for Re = 438

a) Circular b) Diamond



(a)



(b)

Fig -3: Temperature distribution for Re= 876
a) Circular b) Diamond

3.2 Variation of Nusselt number with Reynolds number

Figure 4 shows the variation of average Nusselt number with Reynolds number for circular and diamond shaped tubes. It can be seen that Nusselt number increases with the increase in Reynolds number for both tube shapes. Also Diamond shaped tube offers higher heat transfer rates in comparison to circular shaped tube for all the range of Reynolds number considered in the present study.

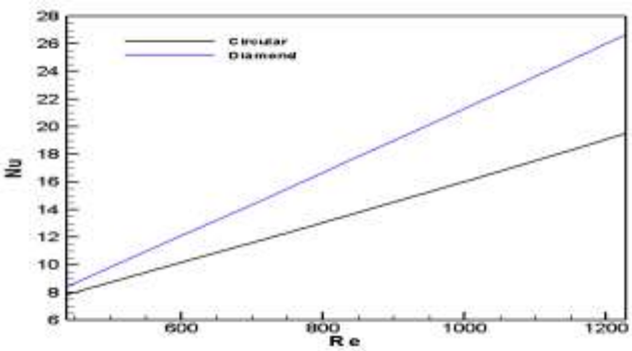


Fig -4: Variation of Average Nusselt number with Reynolds number

4. Conclusions

In the present study, circular and diamond shaped tubes were studied for heat transfer characteristics. Hydraulic diameter for both shapes was kept fixed. Both tubes were subjected to same heat flux of 1000 W/m^2. From the numerical results, following conclusions can be made:

1. From temperature distribution, maximum surface temperature was observed for circular shaped tube in comparison to diamond shaped tube. Also at higher Reynolds number, lower surface temperatures were observed for both tube shapes.

2. Nusselt number for both tube shapes increased with the increase in Reynolds number.

3. Tube shape has a significant effect on heat transfer characteristics. Diamond shaped tubes offer higher values of Nusselt number and hence better heat transfer characteristics than circular shaped tubes. This improvement in heat transfer rate will be beneficial in designing a heat exchanger

REFERENCES

[1] Çengel, Yunus A. Heat Transfer: A Practical Approach. Boston, Mass: WBC McGraw-Hill, 1998.

[2] T.Ota, H. Nishiyama, and Y. Taoka, “Heat transfer and flow around an elliptic cylinder,” Int. J. Heat Mass Transfer, vol. 27, no. 10, pp. 1771–1779, 1984.

[3] J.W.Baughn, M.J.Elderkin, A.A.McKillop, “Heat transfer from a single cylinder, cylinders in tandem, and cylinders in the entrance region of a tube bank with a uniform heat flux,” J Heat Transfer 108(2) (1986), 386–391.

[4] A.Bejan, A.J.Fowler, G.Stanescu, “The optimal spacing between horizontal cylinders in a fixed volume cooled by natural convection,” Inter J Heat Mass Transfer 38(11) (1995), 2047–2055.