

Investigation of Fluid Flow Characteristics for the Forced Convection of Air over Heated Elliptical Shaped Tube

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Abstract - The present study considers the steady, incompressible and laminar fluid flow over a heated elliptical 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 elliptical and circular shaped tube. The Reynolds number range for the present study was varied from 438 to 1227. The governing equations were solved using an academic CFD COMSOL Multiphysics 5.2a software. Fluid flow characteristics such as pressure drop and friction factor were then studied for circular and elliptical shaped tubes. The results showed that Pressure drop for both shapes increased with the increase in Reynolds number whereas friction factor decreased with the increase in Reynolds number. However elliptical tubes showed lower values of pressure drop and friction factor values than circular shaped tube.

Key Words: Elliptical shaped tubes, Hydraulic diameter, CFD, COMSOL Multiphysics, Pressure drop, Friction factor.

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. 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. The fluid approaching the cylinder branches out and encircles the cylinder, forming a boundary layer that wraps around the cylinder. The fluid particles on the mid plane strike the cylinder at the stagnation point, bringing the fluid to a complete stop and thus raising the pressure at that point. The pressure decreases in the flow direction while the fluid velocity increases. At very low upstream velocities, the fluid completely wraps around the cylinder and the two arms of the fluid meet on the rear side of the cylinder in an orderly manner. Thus, the fluid follows the curvature of the cylinder. At higher velocities, the fluid still hugs the cylinder on the frontal side, but it is too fast to remain attached to the surface as it approaches the top of the cylinder. As a result, the boundary layer detaches from the surface, forming a separation region behind the cylinder. Flow in the wake

region is characterized by random vortex formation and pressures much lower than the stagnation point pressure.[1] The present study aims to study fluid flow characteristics of elliptical 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 fluid flow over an elliptical shaped tubes using CFD software COMSOL Multiphysics 5.2a.
2. To compare the fluid flow characteristics such as pressure drop and friction factor for both circular and elliptical shaped tubes.

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 $\alpha = 60^\circ$ - 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 elliptical 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:

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

- ii. Momentum Equation:

$$\vec{V} \cdot (\nabla \vec{V}) = -\nabla P + \nu \nabla^2 \vec{V}$$

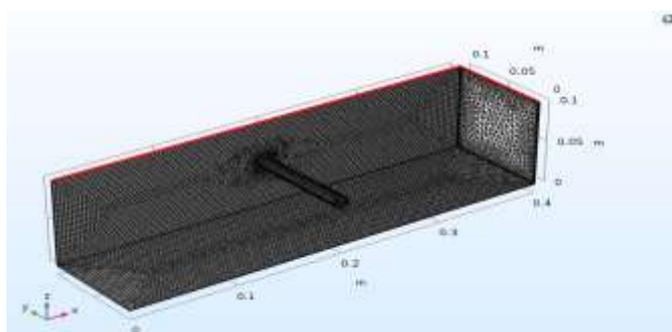
- iii. Energy Equation:

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

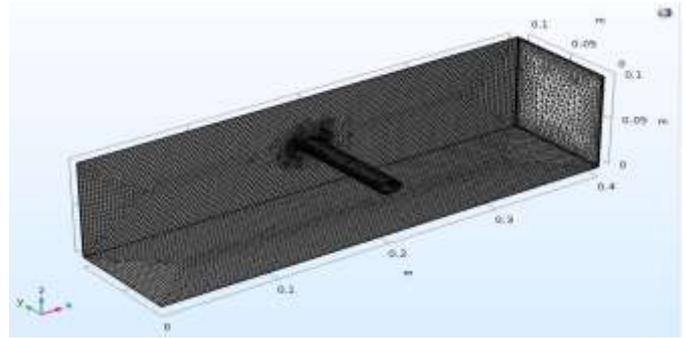
No slip boundary condition was assigned to boundaries where velocity components are set to zero. At the start, the tubes and the channel walls were assumed to be at 293.15 Km2. In all the simulations, the tube surfaces were subjected to uniform heat flux of 1000 W/m².

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 elliptical and circular shaped tubes as 665267 and 491599 respectively. The meshed geometries are shown in figure 1.



a)



(b)

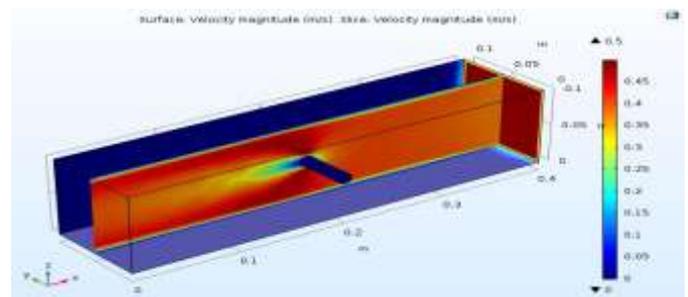
Fig -1: Meshed geometry a) Circular b) Elliptical

3. Results and discussion

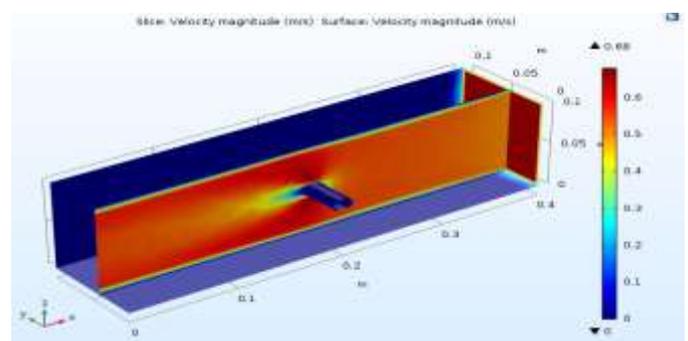
This section shows the simulation results for Velocity distribution, variation of pressure drop with Reynolds number and variation of friction factor with Reynolds number.

3.1 Velocity Distribution

Figure 2 and Figure 3 shows the Velocity distribution for circular and elliptical shaped tubes for the Reynolds number of 438 and 876 respectively. From the figure, it can be seen that velocity at the tube surface is equal to zero because of the no-slip boundary condition. Also large wake can be seen to occur in case of circular shaped tube compared to elliptical shaped tube.



(a)



(b)

Fig -2: Velocity distribution for Re = 438

a) Circular b) Elliptical

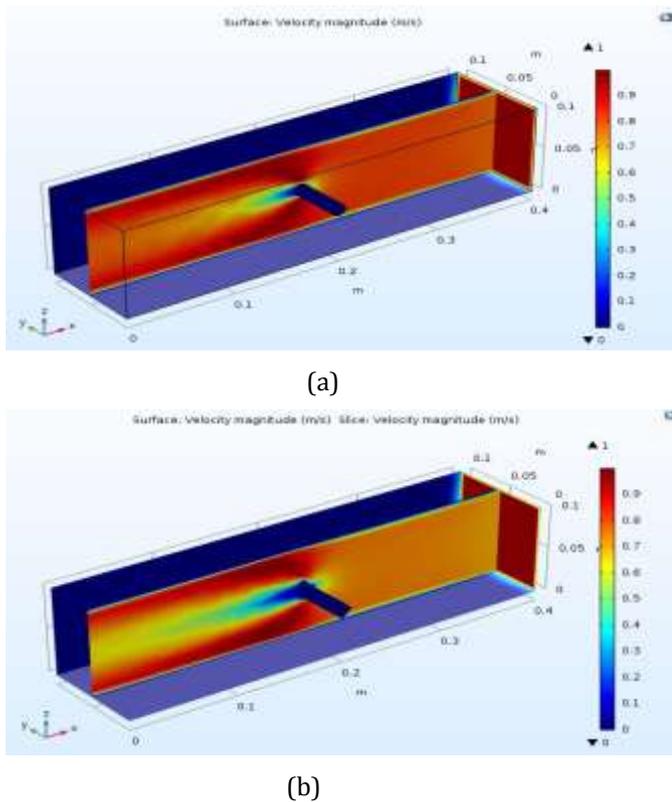


Fig -3: Velocity distribution for Re = 876

a) Circular b) Elliptical

3.2 Variation of Pressure drop with Reynolds number

Figure 4 shows the variation of Pressure drop with Reynolds number for circular and elliptical shaped tubes. Pressure drop can be seen to increase with the increase in Reynolds number for both tube shapes. Also it can be seen that elliptical shaped tube shows lower pressure drop values than circular tube because of the smaller frontal area.

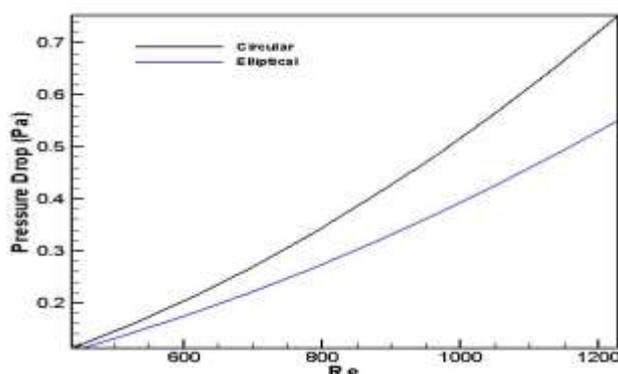


Fig -4: Variation of Pressure drop with Re

3.2 Variation of Friction Factor with Reynolds number

Figure 5 shows the variation of Friction factor with Reynolds number for circular and elliptical shaped tubes.

Friction factor can be seen to decrease with the increase in Reynolds number for both tube shapes. It can be seen that elliptical shaped tube showed lower friction factor values than the circular tube.

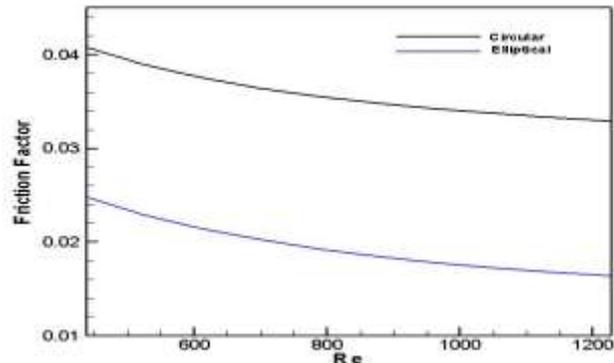


Fig -5: Variation of Friction factor with Re

4. Conclusion

In the present study, circular and elliptical shaped tubes were studied for heat transfer characteristics. Hydraulic diameter for both shapes was kept fixed. The Reynolds number was varied from 438 to 1227. Following conclusions can be drawn from the current study:

1. From Velocity distribution, it was observed that velocity at the tube surface is equal to zero in order to satisfy no-slip boundary condition. Also comparatively smaller wake was observed in case of elliptical shaped tube because of smaller frontal area.
2. Pressure drop values increased with the increase in Reynolds number for both tube shapes. However elliptical shaped tube showed lower pressure drop values than the circular one.
3. Friction factor was seen to decrease with the increase in Reynolds number for both tube shapes. However elliptical shaped tube showed lower friction factor values than the circular tube.

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