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FLUID FLOW AND HEAT TRANSFER AROUND SEMI-CIRCULAR CYLINDER: A REVIEW

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ABSTRACT

Fluid Flow around bluff bodies such as circular, elliptical, square, semi-circular and triangular cylinders was being studies well from several years and there are extensive literatures available on the fluid flow around a circular cylinder because of its practical importance in hydrodynamics and aerodynamics applications and the fundamental significance in the flow physics. On the other hand, semi-circular cylinders are now being studies because of its fluid dynamic features that offers strong engineering applications and tremendous fundamental importance. Fluid flow around a semi-circular cylinder have some practical applications in electronic cooling, heat exchange systems, processing of foodstuffs, etc. The literature available on flow over semi-circular cylinder deals mainly the following parameters i.e. boundary layer separation, forces such as drag and lift and characteristics of the wake region, the nature of the vortex street, the flow separation phenomenon, Nusselt number and strouhal number. Most of the scientists and researchers uses CFD approach to understand various engineering parameters at different values of Reynolds number(Re) & Prandtl number(Pr). It is concluded that as the values of Reynolds number increases, the value of Drag Coefficient decreases and value of Nusselt number increases for low Reynolds number range (0.01-200) in laminar model.

***Keywords:* Semi-Circular Cylinder, Numerical Simulation, Reynolds number, Prandtl Number and Nusselt Number.**

I. INTRODUCTION

The Fluid Flow over bluff bodies of various shapes constitutes an important branch of fluid mechanics and consequently, it has been studied well over 100 years. Over the years, considerable research efforts have been directed at furthering our understanding of the flow of fluids past cylinders of various cross-sections, especially circular, elliptic and square, rectangular and triangular cylinders. The interest of this type of study originates from both practical and theoretical standpoints. From a practical point of view, the flow past a single cylinder denotes an idealization of several industrially important processes or in many process engineering applications, heating and cooling of variously shaped objects are encountered in a range of industrial settings. From a theoretical point, flows over a bluff body constitute an important class of problems within the domain of fluid mechanics and heat transfer which involves studies of different phenomena and parameters such as: wake characteristics (i.e. wake length, wake width, etc.), vortex shedding, drag coefficient, lift coefficient, isotherm, local distribution of Nusselt number and average Nusselt number etc. which often serve as a launching pad to investigate other body shapes as well as interactions between multiple bluff bodies as encountered in numerous applications.

The flow and heat transfer characteristics are the functions of the field variables (*Re, Pr, Ri, local Nu* and *Nuavg*), body geometry and degree of confinements. Such model flow configurations represent the idealization of many real problems and processes encountered in nature and in technology as well. Specifically, recent engineering and industrial applications are frequently using noncircular tubes in heat transfer applications. Semi-circular cylinder is of particular interest for chemical and food industries (e.g. thermal processing of sliced carrot along their long axis), solar engineering applications, flow over semi-circular tubes in novel heat exchangers, electronic cooling and some of the submarines with their flat base can be visualized in terms of the flow over a semi-circular cylinder. Additional applications are found in polymer processing operations where the most of the fluids exhibit non-Newtonian behaviour and variously shaped objects are used as flow dividers. The flow and heat transfer characteristics are influenced by large number of factors such as the number of obstacles, cross sectional shape and orientation of the bluff body, the nature of approaching flow (laminar or turbulent) and the type of the fluid (compressible or incompressible), nature of confinement, operating range of Reynolds number and angle of incidence, etc.

Typical examples include the flow in tubular and pin-type heat exchangers, cooling towers, chimney, compact heat exchangers, cooling components, processing of fibrous suspensions. Further practical applications are found in the use of screens to dewater coal-water slurries, filtration of sewage sludge and polymer melts, removal of oversized particles from coating suspensions.

II. LITERATURE REVIEW

This section presents a review of the previous work related to the flow and heat transfer across various shapes of cylinder like circular, square cylinders, semi-circular etc. The fluid flow and heat transfer from a cylinder immersed in streaming fluid is influenced by large number of variables such as type of fluids (whether linear 0r power-law fluids) body shape, confinement, blockage ratio, *Re*, *Pr* etc. Extensive numerical/experimental literature is available on the forced flow and heat transfer around a semi-circular cylinder in the unconfined domain.

Kiya et al. (1975) [1] investigated numerically the fluid flow past semi-circular and semi-elliptical projections attached to a plane wall for Reynolds number (Re) ranging from 0.1 to 100. They reported geometrical shapes of front and rear standing vortices, drag coefficients, pressure and shear-stress distributions as functions of Re. The drag coefficient of semi-circular and semi- elliptical is nearly same and having more value than circular cylinder and this fact can be interpreted as an increase in the vorticity on the semicircle which is caused by the primary vorticity in the approaching shear flow.

Forbes and Schwartz (1982) [2] the two-dimensional steady flow of a fluid over a semicircular obstacle on the bottom of a stream are discussed. The nonlinear free-surface profile is obtained after solution of an integrodifferential equation coupled with the dynamic free-surface condition. The wave resistance of the semicircle is calculated from knowledge of the solution at the free surface and (1988) again they further presented numerical solutions for the problem of two-dimensional "critical" flow of an ideal fluid over a semi-circular obstacle attached to the bottom of a running stream. The upstream Froude number and downstream flow speed are unknown in advance, and are therefore computed as part of the solution. The dependence of flow behavior on obstacle size is discussed.

Kumarasay and Barlow (1995) [3] The flow around a half cylinder placed at various gap ratios above a plane wall was investigated experimentally. Effect of gap ratios on Strouhal number was found from the spectra of unsteady pressures measured at the separation points. Distribution of mean pressure around the cylinder and along the wall were measured at a Reynolds number based on base height, of 4.67 x. For the. Critical gapratio, under which periodic vortex shedding vanished was found to be *0.33* times the base height, D. Length of the wall, hence, the boundary layer thickness did not have any noticeable effect on the critical gap ratio. Inviscid instability associated with two vortex streets is examined to explain the high critical gap ratio.

Boisaubert et al. (1996) [4] experimentally analyzed the flow over a semi-circular cylinder for flat and round sides facing the flow using a solid tracer visualization technique for Re = 60–600. They found that critical Reynolds numbers for the onset of vortex shedding as 140 and 190 for flat and curved surfaces, respectively.

Boisaubert and Texier (1998) [5] investigated the effect of gap between the semicircular and the splitter plate on the wake was obtained. The wake length increased with increasing in the value of Re. Addition of a splitter plate along the wake centerline downstream from bluff bodies is an efficient passive means of controlling fully developed vortex shedding. The objective of this work is to observe, by means of solid tracer visualizations, the influence of such plate control on the early near-wake establishment stages of a semi-circular cylinder (SCC) geometry.

Coutanceau et al. (2000) [6] explained not only the way of formation of the initial wake vortices (primary and secondary vortices), but also their development with time behind a short cylindrical semi-circular shell. They reported about regime where structure changes occurred beyond the first phase of development when Re was between 120 and 140.

Kotake and Suwa (2001) [7] investigated the variation of stagnation points and the behaviour of vortices in the rear of a semi-circular cylinder in the uniform shear flow by the visualization technique of the hydrogen bubble method. They showed that in case of shear flow, there was no vortex on the side with the faster main stream speed and the vortices were generated only on the slower speed side.

Iguchi and Terauchi (2002) [8] studied the three kinds of noncircular cylinders (e.g. semi-circular, triangular and rectangular) to detect the shedding frequency of Kármán vortex streets for velocity lower than 10 cm/s. A triangular cylinder was found to meet the requirement most adequately as long as minimum detectable velocity was approximately 5 cm/s in the direction of flow approaching the triangular cylinder.

Sophy et al. (2002) [9] examined the flow past a semi-circular cylinder with curved surface facing the flow and found the flow to be unsteady at Re = 65. They obtained the corresponding Strouhal number as 0.166, which was 7% larger than that of a circular cylinder at the corresponding transition.

Koide et al. (2003) [10] investigated the synchronization of Kármán vortex shedding by giving a controlled crossflow oscillation to circular, semi-circular and triangular cylinders. They showed that the synchronization region was almost the same for the three cylinders in spite of the different behaviours of separation point at high Re = 3500 and further Koide et al. (2003) [11] also experimentally investigated the influence of the cross-sectional configuration of a cylindrical body on Kármán vortex excitation by using the same cylinders. They found that Kármán vortex excitation appears on all the three cylinders, but the oscillation behaviour was drastically different among them.

Nada et al. (2003) [12] Experimental study, Free convection, 109≤*Re*≤6×109. The convective heat transfer coefficient was found as a function of the Rayleigh number, inclination angle, and orientation angle of the semi-circular cylinder. The *Nu* increased with the angle of inclination. *Nada et al. (2007) [13]* Experimental and numerical study, 2.2×103≤*Re*≤4.5×109. The *Nuavg* increased the angle of attack. The *Nuavg* increased with increase in Reynolds number

Hocking et al. (2008) [14] Numerical study, 0 ≤Froude number ≤5. The results were presented to show the influence of gravity on wake size for the flow over a semi-circular cylinder. They found narrow and long wake region for the upward facing curved surface configuration and wide and short wake region for the downward facing curved surface configuration

Chandra and Chhabra (2011) [15] Numerical, Steady mixed convection, 0≤ *Ri* ≤2, 1≤ *Re* ≤30, 1≤ *Pr* ≤100, 0.2 ≤*n*≤6. At *Re*=1, *Nu* was found to be maximum at corners and for high *Re*, it shifted towards the front stagnation point. The *Nuavg* increased with *Re*, *Pr* and *Ri*.

Chandra and Chhabra (2011) [16] Numerical, Steady forced convection, 0.01≤ *Re* ≤30, 1 ≤ *Pr* ≤100, 0.2 ≤*n*≤1.8. The *CD* decreased with increase in *Re*, for *n*<1 at low *Re*. The *Nuavg* increased with *Re*, *Pr* and *Ri*. Heat transfer increased with the higher value of power law index.

Chandra and Chhabra (2012) [17] Numerically, Free convection, 10≤*Gr* ≤105, 0.72≤ *Pr*≤100, 0.2≤*n*≤1.8. The *Nuavg* increased with *Gr* and *Pr*. The flow remains attached to the surface of the semi-circular cylinder for *n*>1.

Bhinder et al. (2012) [18] numerically investigated the forced convective heat transfer characteristics past a semi-circular cylinder at incidence for Re = 80–180 and Pr = 0.71. They showed that the increase in angle of incidence increases streamline curvature. Strouhal number showed a decreasing trend up to certain values of angle of attack and thereafter it increases marginally. A correlation of Strouhal number as a function of Re and angle of attack was established.

Chatterjee et al. (2013) [19] A 2D Numerical simulation for unsteady flow is performed on two different configurations of the semicircular cylinder facing the flow to investigate the laminar forced convection heat transfer for Re ranges from 50 to 150 with a Pr=0.71 & for fixed blockage ratio β=5%. The flow quantities, such as the drag and lift coefficients, are found more for when flat surface faces the flow. It is observed that the heat transfer rate is enhanced substantially when the curved surface is facing the flow in comparison to the case when the flat surface is facing the flow.

Sukesan and Dhiman (2014) [20] investigated Effects of cross-buoyancy mixed convection on flow and heat transfer characteristics of a long semi-circular cylinder (long in neutral direction) in a confined channel have been investigated in the laminar regime. The numerical results have been presented and discussed for the range of conditions as Reynolds number (Re) = 1–40, Richardson number (Ri) = 0–4, Prandtl number (Pr) = 0.71–50 and blockage ratio (β) = 16.67%–50%. The drag coefficient increases with increasing Richardson number and/or blockage ratio. The average Nusselt number is showing a maximum relative enhancement of approximately 45% for Ri = 4 with respect to corresponding forced convection value (Ri = 0). The average Nusselt number increases with increase in Prandtl number and shows a maximum relative enhancement of approximately 1136% for Pr = 50 with respect to corresponding value at Pr = 0.71.

Tiwari and Chhabra investigated (2014) [21] the flow of power-law fluids past a semi-circular cylinder with its flat face oriented upstream for Re = 0.01–25, n = 0.2–1.8 and Pr = 0.72–100. The critical Reynolds number for the onset of wake formation for a semi-circular cylinder with its curved face oriented in the upstream direction is found lower than that of a semi-circular cylinder with its flat face oriented in the upstream direction. In contrast, the critical Reynolds number for the onset of vortex shedding for a semicircular cylinder with its curved face oriented in the upstream direction is found a little higher than that of a semi-circular cylinder with its flat face oriented in the upstream direction.

Kumar et al. (2015) [22] A numerical analysis was carried out to investigate the forced convection of power law fluids (n= 0.2 to 1.8) around a heated semi-circular cylinder with blockage ratio, β=25%, Pr = 50, and Re 1–40. The shear-thickening behavior was found to have a higher value of drag coefficient(Cd), whereas the shear-thinning behavior had a smaller value of Cd as compared with Newtonian fluids in the steady regime. The wake size was found shorter in shear-thickening fluids than Newtonian and shear-thinning fluids. The Nuavg were observed higher for shear-thinning fluids than Newtonian and shear-thickening fluids; and the maximum enhancement in the heat transfer was achieved approximately 47% as compared to Newtonian fluids. In addition, the effects of blockage ratios ranging from 16.67% to 50% on the engineering output parameters with varying power law index at Re = 40 were reported.

Kumar et al. (2016) [23] the 2D simulations are carried out for varying values of control parameters: Reynolds number (Re) = 50–200 and Prandtl number (Pr) = 0.7, 10 and 100 at a fixed blockage ratio of 25% for Newtonian constant-property fluid around a heated semi-circular cylinder for unsteady regime. The transition from steady to time-periodic flow occurs between Re = 69 and 70. The effect of Prandtl number on Nusselt number is pronounced; the ratio of Nusselt number values belonging to Pr = 100 and those belonging to Pr = 0.7 ranges from 6.3 to 6.5 over the Reynolds number domain investigated. An overall heat transfer is increases with the Reynolds number(Re)

III. MODEL FORMULATION AND SOLUTION METHODOLOGY

In order to understand the liquid flow and heat transfer over a semi-circular cylinder placed in a confined channel of the present study, following assumptions are employed: -

(1) uniform flow at inlet. (2) steady, laminar flow, (3) axial thermal conductivity, and (4) viscous dissipation, (5) varying fluid thermal-physical properties.

Based on above assumptions, dimensionless form of governing equations can be written as follow:

- **Continuity equation: -**

$$\nabla \quad = 0 \qquad (1)$$

- **Navier-Stokes Momentum equation: -**

$$= - \nabla p + \quad \nabla^2 \qquad (2$$

- **Energy Equation: -**

$$= \qquad \nabla^2 \qquad (3)$$

The governing equations are solved using the computational fluid dynamics solver ANSYS FLUENT 15.0. The SIMPLE algorithm is used to solve these governing equation for velocity, pressure and temperature in the control volume. The standard discretization scheme is used in the modelling following the second order upwind scheme for momentum and energy discretization.

IV. CONCLUSIONS

From the brief study of extensive literature available we have concluded that the flow around a bluff bodies is not remaining steady throughout the flow and its became unsteady after a certain values of Reynolds number that Reynolds number is known as critical Reynolds number and its values is different for different conditions and bodies overt which flow is taking places.

Further it is also concluded that the value of drag coefficient (CD) is decreases with Reynolds number and Lift Coefficient (CL) is increases with the Reynolds number and the value of Nusselt number is increases with the Reynolds number and Prandtl number.

Further it is concluded that the value of drag coefficient for semi-circular cylinder is less than the circular cylinder.

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