Abstract

Flow around circular cylinder is a complex which involves both quantitative calculations and qualitative judgments and it plays a very significant role in engineering application. When a flow goes across a circular cylinder, complex flow phenomena and behaviors in the vicinity of the cylinder surface and the wake region, e.g. flow separation, vortex shedding and shear-layer instability etc., are usually induced in different regimes of Reynolds numbers. These flow phenomena would inevitably apply unsteady lift and drag forces to the cylinder. In the absence of external forces, the dynamics of flow around a cylinder depends only on the Reynolds number.

Passive control is one of the flow control techniques for reducing the aerodynamic drag exerted on a bluff body. It controls the vortex shedding by modifying the shape of the bluff body or by attaching additional devices in the flow stream. In this paper the heat transfer and pressure drop behaviour of circular cylinder is investigated with different attachments as splitter plate (L=D, L=1.5D and L=2D) and V-shaped profile.

1. Introduction

Bluff body is a widely studied problem since the study of Strouhal (Strouhal, 1878) who observed vortex shedding from a circular cylinder. Most of works were carried out on the cylinders having circular, square and rectangular cross-section, but the flow around circular cylinders remains the principal subject of researchers because, despite the geometric simplicity, the mechanisms involved are complex and the flow patterns are not easy to investigate.

When a circular cylinder is placed into the flow, the fluid flow separates from the body as result of pressure gradient increment. This can cause periodic shedding of vortices from the body. When the vortex shedding occurs behind a cylinder, drag on the cylinder increases and the body suffers from the periodic force in the normal direction to the main stream. This force makes the life of the structure shorten. On the other hand, the vortex shedding enhances mixing behind the cylinder. The vortex shedding significantly depends on the Reynolds numbers based on the cylinder diameter. When a fluid flow occurs over a curved surface, at the downstream side of a cylinder at sufficiently high velocity, the boundary layer will no longer remain attached to the surface, and this process of separation known as flow separation as shown in Figure 1.
The pressure is maximum at the stagnation point and slowly decreases along the front half of the cylinder. This is favourable pressure region as expected. Yet, if the pressure starts to rise in the rear half of the cylinder, the flow will separate from the surface and a turbulent region behind the cylinder will be created. This region of recirculating flow immediately behind a solid body, caused by the flow of surrounding fluid around the body is called the “wake”. The boundary layer which leaves from the surface forms a free shear layer. This shear layer will eventually roll into a discrete vortex and detach from the surface. This is called “vortex shedding”.

Several control methodologies have been suggested to modify vortex shedding behind a circular cylinder and to effectuate drag reduction, either with passive geometrical modifications and/or with an open loop steady forcing. Passive control is one of the flow control techniques for reducing the aerodynamic drag exerted on a bluff body. It controls the vortex shedding by modifying the shape of the bluff body or by attaching additional devices in the flow stream. Addition of splitter plate is one of the Passive flow control method. Roshko (1954) carried out an experimental investigation of circular cylinder by placing a splitter plate in the downstream direction of the wake at Re = 14,500. It was observed that flow pattern changes. When the length of splitter plate was 5D, the vortex shedding completely disappeared and pressure drag was significantly reduced. Moreover when the splitter plate was detached and move 3.85D downstream from the cylinder exhibits the shedding frequency become minimum and the base pressure was maximum. A splitter plate of length 1D did not inhibit formation of vortices but changed the shedding frequency slightly.

Gerrard (1996) conducted experiments to studied the formation region behind circular cylinder at Re = 2 x 104. It was found that the Strouhal number decreased when the length of the splitter plate was smaller than d, but it increased for d<1<2d. Addition of splitter plate increased the production of circulation at the rear of the cylinder, as a result the vortex strength in the early stage of growth decreased. The effective formation-region length was the distance from the plate to the end of the region. It was found that when the vortex was growing close behind the plate, there was a large cross-flow velocity produced near the plate, assist the shedding process and increase the frequency. Hwang et al. (2003) numerically studied flow induced forces on a circular cylinder using detached splitter plate considering the laminar flow. A splitter plate with the same length as the diameter of cylinder was placed horizontally in the wake region. Suppressing the vortex shedding, the plate significantly reduced drag force and lift fluctuation.

Akilli et al. (2008) investigated experimentally passive control of vortex shedding by splitter plates having L/D ratio (0.2 to 2.4) attached on the cylinder base in shallow water flow at Re = 6300. In this study, the length of the splitter plate was varied from in order to see the effect of the splitter plate length on the flow parameters. Razavi et al. (2008) carried out numerical investigation of flow and heat transfer around circular cylinder in the range of 20 < Re < 1000 by finite volume method. It was concluded that splitter plate streamlined the flow around the cylinder and accordingly decreased the pressure drag causing the significant reduction in overall drag. The heat transfer decreased from the surface of a cylinder, whereas placing the splitter plate increased the total heat transfer.

2. Experimental set-up

The experimental investigations were carried out in an open circuit wind tunnel which is schematically shown in Figure 2.1. Ambient air was taken from a axial fan and the air flow was controlled by an electric regulator. The test section has a cross sectional area of 200 mm x 250 mm and is 300 mm long. The investigations were carried out on test section of circular cylinder; circular cylinder with splitter plate and V shaped profile.

Test cylinder and splitter plate made of Aluminium. The cylinder diameter (D) was 50 mm and 200 mm in length while the splitter lengths used was L = D (Length = 50mm and width=200mm) and the plate thickness was 1.2 mm. It was placed in longitudinal slot into the base cylinder at Φ = 180° as shown in Figure 2.2. The splitter plate has an interference fit with the cylinder slot for rigidity. Heat transfer measurements were done pencil type heater, placed concentrically inside test cylinders made of Aluminium. Heaters were regulated by a dimmer stat. Copper-constantan thermocouples were fixed on the cylinder and the splitter surfaces in order to measure the wall temperature. The thermocouples were positioned at intervals of 45° around the test cylinder as shown in the figure 2.2.
2. Results and discussion

Graph (3.1 and 3.2) shows the variation of heat transfer coefficient in circumferential direction. The angle ($\theta$) is measured from the front stagnation point. Behaviour of Nusselt number for different passive control method is shown. The heat transfer coefficient decreases gradually from front stagnation point towards the separation point. The heat transfer coefficient has the minimum value near the separation point. After the separation point the heat transfer coefficient increases because of the considerable turbulence exists over the rear side of the tube where eddies of the wake sweep the surface in case of circular tube without splitter plate.
For comparison of Nusselt number distribution on the circular tube with the Nusselt number distribution on the splitter plate and V-shaped profile, Graph 3.2 and 3.4 shows the variation of Nusselt number along length of the splitter plate (from \( L=0 \) to \( L=0.05m \)) and V-shaped profile (\( L=D \)). Splitter plate is attached in a longitudinal slot into circular tube at \( \theta=180^\circ \). Therefore Nusselt number on circular tube at \( \theta=180^\circ \) and splitter plate length (\( L = 0 \)) is assume to be same.

The splitter plate reduces the size of the wake zone by streamlined the fluid flow. As the wake region gets narrow, convective heat transfer from the tube surface decreases. But by the graph it is shown that the presence of the splitter plate increases the total heat transfer substantially by generating an extra fin area for conduction. Overall, there is an enhancement in heat transfer from circular cylinder with splitter plate compared circular cylinder without splitter plate. Value of Nusselt number was found to be high at tip of splitter plate than its base. From the figure it is also shown that as the Reynolds number increases, heat transfer coefficient of splitter plate increases.

It is observed that V-Shaped profile plate attached downstream of the circular cylinder has low heat transfer rate at \( \theta=180^\circ \) as there is no contact of cylinder surface with fluid flowing over it.

Graph 3.1 shows the Nusselt number distribution along the circumference of the circular cylinder, circular cylinder with splitter plate and V-shaped profile at an interval of 45° for Reynolds number 10000.

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Graph 3.2 Nusselt number distributions on Splitter plate and V-shaped profile

Graph 3.2 shows the Nusselt number distribution along the length of splitter plate V-shaped profile for Reynolds number 10000.

Graph 3.3 Temperature distributions over circular cylinder for Reynolds number 8000

Graph 3.3 shows the temperature distribution over a circular cylinder for Reynolds number 8000, comparing cases with and without a splitter plate and a V-shaped profile.
Graph 3.3 shows the Nusselt number behaviour along the circumference of the circular cylinder, circular cylinder with splitter plate and V-shaped profile at an interval of 45° for Reynolds number 8000.

Graph 3.4 shows the Nusselt number distribution along the length of splitter plate V-shaped profile for Reynolds number 8000.
Pressure drop is measured for different Reynolds number and it is found that pressure drop across circular cylinder with splitter plate is lower than pressure drop without splitter plate. As the addition of splitter plate creates a streamlined extension of the circular tube, reducing the size of the wake zone by moving vortices towards the plate and roll over the edge. Therefore turbulence in wake region reduces, which causes decrease in pressure drop.

However V-shaped profile provides maximum reduction in pressure drop but on the expense of lower heat transfer rate shown in Graph 3.1 and 3.3.

3. CONCLUSIONS

Integration of Passive flow control techniques in the down stream side of the circular cylinder alters the flow behaviour significantly. The rate of heat transfer increase considerably with the decrease in power required for pumping. It was observed that heat transfer from circular cylinder with passive flow control technique was more than circular cylinder. V-Shaped profile plate attached downstream of the circular cylinder provides maximum reduction in pressure drop but has low heat transfer rate. Addition of splitter plate in the down stream side of the circular cylinder shows the enhancement in the heat transfer with decrease in pressure drop.

4. REFERENCES


