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Experimental Review on Influence of Inlet Disturbance Body (IDB) at 30º Against Inhibitory Force Reduction on Three Circular Cylinders with Composed of Stagger (Variation L/D(constant=2), T/D= 1.5, 2, 3 & 4)

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Abstract. Research on the characteristics of the fluid flow across the bluff body has been carried out and placed in a variety / setting, let alone research on fluid flow across three circular cylinder arranged stagger by placing 2 (two) Inlet Disturbance Body *(IDB)* as a bully in front. This effort is usually done to reduce the normal force, shear force, and drag force that occurs in the bluff body of the three circular cylinders. This research was conducted experimentally in mechanics laboratories and fluid machines using subsonic wind tunnels and tested at Re = $2.2x10^4$ based on the diameter of a circular cylinder. Variations used are longitudinal distance ratio (L/D) = 2 with a circular cylinder diameter (D = 25 mm) and transverse distance ratio (T/D) = 1.5, 2, 3 and 4 and *IDB* placement on the upper and lower sides from cylinder 1 (upstream) in the form of a cylinder with a diameter (d = 4mm) at 30 °. The results showed that the use of IDB at position 30º can reduce the drag force that occurs in cylinder 1 (upstream) 36 to 53% compared to with no *IDB*, while for cylinder 2 (upstream), the drag is higher for (T/D) = 1.5, 2 and 3 are 3.2 to 22% and at (T/D) = 4 the drag force is reduced to 9% again. About cylinder 3 (downstream - down) in the stagger configuration with IDB 30º, the drag is 4.8 to 44% higher for all distance variations (T/D) compared to the stagger configuration with no *IDB*. Variation in distance (T/D) also greatly affects the distribution of pressure coefficients that occur with the three circular cylinders with a stagger arrangement, causing a difference in the distribution of the drag pressure coefficient (C_{DP}) and also the velocity profile behind the 3 circular cylinders with the stagger arrangement.

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1. Introduction

Several types of body geometry applications have been widely used in the engineering world, one of which is a circular cylinder. The use of circular cylinders in the world of engineering such as subsea pipelines, pressurized vessels, bank tubes, high-voltage electric cables, steel frame bridges, suspension bridges and towering industrial chimneys is increasingly being used. This condition allows researchers to continue to study the forces that occur in the installation, in an effort to reduce drag, this research was carried out.

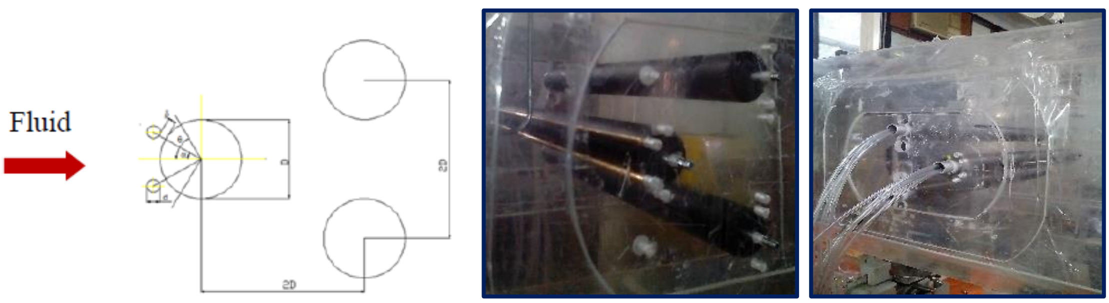
Research to reduce drag has been carried out [1], who examined the flow across two circular cylinders arranged in tandem by adding a disturbing body in front of the upstream cylinder. Tested on subsonic wind tunnel open circuit wind tunnel with ReDh 1,56x105 and circular cylinder diameter size D = 24 mm and inlet disturbance diameter body d = 4 mm. The distance between cylinders is $1.5 \leq L/D \leq 4$ and variations in the angle of disturbance are placed at angles $\alpha = 30^o$ and 60^o. The size of the wind tunnel used is 125 mm x 125 mm x 2000 mm. The results obtained show that the addition of the intruder body at an angle of 30 ° can reduce the drag force of the upstream cylinder optimally, but the downstream cylinder drag force is higher than the downstream cylinder drag force in the tandem configuration without the disruptive body. On the contrary, it is shown in a tandem configuration with a 60° interfering body, the upstream cylinder has a higher drag force than a tandem configuration without an interfering body while the downstream cylinder has a lower drag force. The results of [1] also correspond to [2], [3],[4],[5], and [6].

[7], has conducted experimental research on three circular cylinders in the arrangement of equilateral triangles. This navigation is very similar to research conducted [8], experimentally, with the arrangement of equilateral triangles also closed system wind tunnel test with Re = 5.5 x 104 and different angle variations starting at angle $\beta = 0^o$, up to 60^o. Variations used in this study were N/d = 1.7., 2.2., 2.5 and 4.0 and the size of the circular cylinder used was 640 mm long, 48 mm in diameter made of aluminium cylinders. A pressure tap is installed every 10^o on the mid-span in a circular manner on a circular cylinder. The results of the study indicate that variations in distance ratio N/d and different angles greatly affect the flow pattern, pressure distribution and drag coefficient that occur in the three circular cylinders.

Based on the results of the study above a new idea arises to re-examine the effort to reduce drag on three circular cylinders by placing a cylindrical body in the upper and lower positions in front of cylinder 1 (upstream).

2. Methodology

The scheme of the research that will be carried out can be seen in Figure 1 below, which is shown by the location of the test object is three circular cylinders arranged in a stagger with a disturbing body on the front of the main cylinder.



(a) (b) (c)

Figure. 1. (a) Research Installation, (b) Position of circular cylinders with *IDB*, (c) Position of circular cylinders with no *IDB* (in the wind tunnel channel)

The test specimens used in this study were three circular cylinders made of PVC pipe with a length of L = 300 mm and a diameter of D = 25mm and a nuisance body made of brass with a plain surface d = 4mm placed on a narrow channel with a square section (H = 300 mm, W = 300 mm and L = 600 mm) Blockage ratio is 24%. The cylinder position 1 (upstream) is placed at a distance of 200mm from the inlet test section or 50 mm apart from the pitot static tube, the upper and lower downstream cylinders of 2D distance from the upstream cylinder and the pitot static tube position behind the cylindrical arrangement within 4D. The interfering body is placed at an angle of 30° at a constant gap between the cylinder and the disturbing body (δ = 0.4mm). This test is done to say Reynolds based on cylinder diameter is 2.2x104. Calibration is done using pitot static tube placed in front of the cylinder arrangement and connected to the Omega PX655 pressure transducer then connected to the Omega data acquisition DAQPRO-5300 for digital readings in the form of a current in the 4mA-20mA range, the pressure data from the transducer pressure reading above is then processed computationally to get the desired Re value.

3. Results and Discussion

To find out how the flow characteristics across three circular cylinders arranged stagger with two IDBs on the cylinder upstream side and cylindrical arrangement without IDB, will be discussed experimentally through quantitative data obtained from the experimental results. Quantitative data in the form of pressure coefficient (Cp), velocity profile (U / Umaks), and drag pressure coefficient (Cdp). To get the pressure distribution coefficient (Cp) on the surface of the circular cylinder, it is obtained through the equation:

$$C_P = \left(P_C - P\infty\right) \Big/ \tfrac{1}{2}\rho.U_\infty^2 \qquad (1)$$

where: is a circular cylinder pad contour pressure, static pressure on the free-stream, and is the dynamic pressure in the free-stream. Whereas to get the drag pressure coefficient (Cdp) obtained by integrating the pressure coefficient (Cp) of the cylinder surface contour.

$$C_{Dp} = \frac{1}{2}\int_a^b C_p(\theta)\cos(\theta)d\theta \qquad (2)$$

where is the coefficient of contour pressure on the position, and is the angle of the position of each pressure tap on the contour.

The integration used to obtain the pressure drag coefficient is the numerical integration of the Simpson 1/3 method. Common equations are as follows:

$$\frac{1}{2}\int_a^b y(x)dx = \frac{b-a}{2x3n}\left\{y_0 + 2\left(y_2 + \ldots + y_{n-2}\right) + 4\left(y_1 + \ldots + y_{n-1}\right) + y_n\right\} \qquad (3)$$

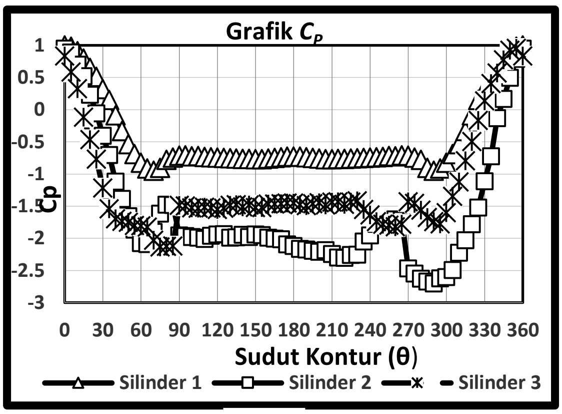
Finally,

$$C_{Dp} = \frac{b-a}{2x3n}\left\{y_0 + 2\left(y_2 + \ldots + y_{n-2}\right) + 4\left(y_1 + \ldots + y_{n-1}\right) + y_n\right\} \qquad (4)$$

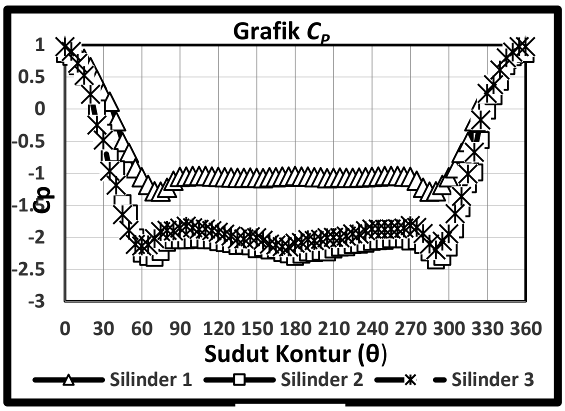
3.1. Distribution of Pressure Coefficients on Three Stagger Circular Cylinders without IDB on T/D 2 and 4

In Figure 2 below, it was displayed a graph of the pressure coefficient distribution on the surface of cylinder 1 (Upstream), cylinder 2 (upper downstream) and cylinder 3 (downstream down). The experimental results show chart trends that are very different for the T/D = 2 transversal distance variation, while for the distance T/D = 4, Cp tends to be more stable. The Cp distribution on cylinder 1, the stagnation point is exactly at a 0° angle. After the point of stagnation, the flow is accelerated which is characterized by a decrease in the graph of the extreme pressure coefficient distribution until the flow has a maximum speed which is characterized by a decrease in the distribution of the pressure coefficient at the lowest position of -0.945. In the upper side position, the flow experiences a maximum speed at an angle of around 65° -70°, while in the lower side position, the flow experiences a maximum speed at an angle of 290° -295°. At one point, the flow is no longer able to fight adverse pressure and friction so that separation occurs which is marked by the coefficient of pressure starting at a steady angle of 90° for upper side and 27° for the lower side. The difference of each variation in distance is seen in base pressure. The lowest base pressure value at a distance of T/D 2 and the highest value at a distance of T/D 4.

The graph of Cp distribution on the surface of cylinder 2 and cylinder 3 with variations of T/D=2 shows a significant difference between the Cp distribution in the upper side and the lower side positions. This condition is caused by the influence of the bistable effect or known as the phenomenon based flow that occurs around the circular cylinder. In bistable distance [3], the Cp distribution is characterized by the formation of a different wake width between the lower cylinder and the upper cylinder. As is well known, that the drag force that occurs behind the cylinder is a narrow wake that is greater than a wide wake on other cylinders, this effect causes a difference in the stagnation points that occur in both circular cylinders. that. For cylinders 2 points the stagnation is at an angle position of 0° and the cylinder 3 points of stagnation are at an angle of 355°.



(a)



(b)

Figure 2. Cp Distribution Chart (a) *T/D*=2*;* (b) *T/D=4* on Confirmed Stragger Without *IDB*

Chart of Distribution Cp for cylinder 1 (Upstream), cylinder 2 (upper downstream) and cylinder 3 (downstream down) at transverse distance T/D = 4, shows almost the same graph trend between the three circular cylinders. The Cp distribution that occurs on cylinder 1 (Upstream) is almost like a Cp chart that occurs on cylinder 1 with a transversal distance T/D = 2, in the stagnation point is exactly at the 0° Cp angle is 1. However, there is a slight difference in the stability level the Cp is, at the transverse distance T/D = 2, the Cp stability is at the value of Cp = -0.710 to -0.767. While at the transversal distance T/D = 4, the stability of Cp is at the value of Cp = -1.042 to -1.076. Judging from the graph shown, graph Cp on cylinder 1 after the point of stagnation, the flow has a significant acceleration which causes the distribution of the pressure coefficient to drop to the lowest. In the upper side position, the flow experiences a maximum speed at an angle of about 75°, while in the lower side position, the flow experiences a maximum speed at an angle of 285°. Then the flow experienced a slowdown due to the adverse pressure effect which is marked by a decrease in speed. At one point, the flow is no longer able to fight adverse pressure and friction so that the separation is characterized by the distribution value of the pressure coefficient starting at a steady angle of 90° for the upper side and an angle of 270° for the lower side.

In cylinder 2 and cylinder 3 for transversal distance T/D = 4, the graph of Cp distribution that occurs shows almost the same graph trend between the two downstream cylinders namely cylinder 2 (top downstream) and cylinder 3 (downstream down). The stagnation point that occurs in both of these downstream cylinders is in the 0° position. Then the fluid flow across the two downstream cylinders experiences maximum acceleration which causes a decrease in Cp to the extreme until the maximum speed on the upper side is around the angle of 70° for cylinders 2 and 60° for cylinders 3, while for the lower side positions the maximum velocity for cylinders 2 and cylinder 3 is equally at an angle of 290°. After passing through the stagnation point, the flow then experiences a slowdown due to the adverse pressure gradient which is characterized by increasing pressure coefficient which causes the flow to no longer be able to fight adverse pressure and friction. This condition causes the flow separation and occurs at an angle range of 70° -270°.

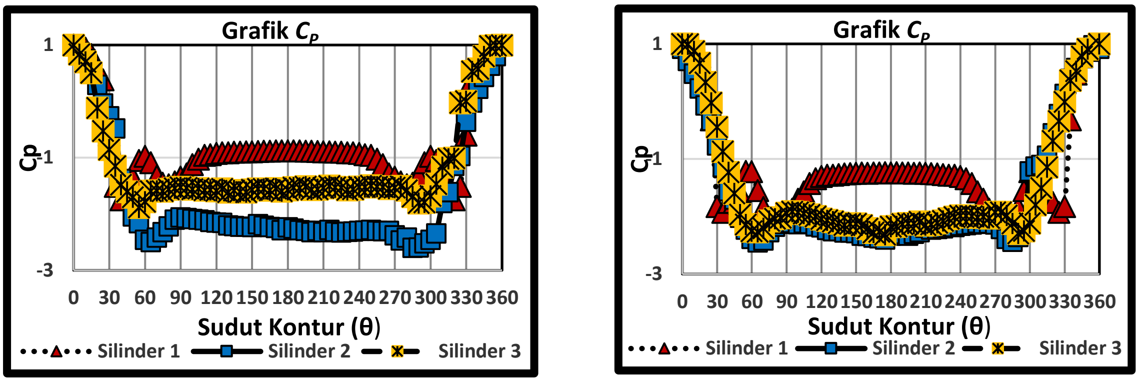
3.2. Distribution of Pressure Coefficients on Three Circular Cylinders composed of Stagger with IDB 30° at T/D 2 and 4

The following is an analysis of the distribution of Cp on three circular cylinders arranged in a stagger with the addition of an Inlet Disturbance Body (IDB) at 30° in front of cylinder 1 (upstream) at transverse distance T/D = 2 and 4 as shown in Figure 4 below. The graph of Cp distribution at a distance of T/D = 2 shows that the stagnation point on cylinder 1 is exactly at an angle of 0° with its Cp value = 1. Then the flow is accelerated which is marked by decreasing Cp up to 40° at its Cp value = -1,751 in the upper side position and at an angle of 320° the Cp value is also the same, namely = -1,751 in the lower side position.

The maximum acceleration of fluid flow is caused by the flow through the favorable area in the form of a diffuser then the Cp increases again to an angle of ± 60° Cp value is -0.977 in the upper side position and 310° angle on the lower side due to the narrowing between the cylinders 1 (upstream) with IDB at 30° position, this condition causes blockage which results in decreased flow momentum. After passing this favorable region, the flow experienced an acceleration due to the parallel flow from the effect of the wake of IDB which caused the shear layer to be released back to re-attachment on cylinder surface 1 which was marked by a peak. Then the flow returns following the cylinder surface contour 1 which marked a decrease in pressure until the separation occurs at ± 115° upper side and lower ± 255° angle.

The Cp distribution chart on cylinder 2 (top downstream) and cylinder 3 (downstream down) for transversal distance T/D = 2 indicates that, in cylinder 2 (upper downstream) there is a slight pressure difference that occurs between the upper side position and the Cp distribution on the position lower side, while in cylinder 3 (downstream) the graph of Cp distribution is more stable both in the upper side and lower side positions. The difference in Cp distribution on cylinder 2 is more due to the effect of bistable effects or known as phenomenon based flow as described in the configuration without IDB above. The bistable effect also causes a stagnation point difference that occurs in both downstream cylinders, namely for the cylinder 2 points the stagnation is at the angle of 5° and the cylinder 3 point of stagnation is at an angle of 0°.

The distribution of the pressure coefficient for cylinder 3 (downstream down), shows that the stagnation point is located at an angle of ± 0° upper side its Cp value is 0.997, then the flow experiences an acceleration which causes the pressure coefficient to drop to an extreme maximum at the upper side around angle 55° Cp value is -1.888, while at the lower side the maximum speed of flow occurs at the angle of 290° Cp -1.808. Then the flow experienced a slowdown due to the adverse pressure which is characterized by increasing the pressure coefficient to an angle of ± 65° in the upper side position and continues to stable its Cp value at an angle of 275° in the lower side position.



(a) (b)

Figure 3. Cp Distribution Chart (a) *T/D* 2*;* (b) *T/D 4* on Confirmed Stragger with *IDB 30°.*

Figure 3b shows a graph of the distribution of Cp at a transverse distance T/D = 4 with the addition of an inlet disturbance body (IDB) at 30° in front of cylinder 1 (upstream), indicating that the momentum of the fluid flow regarding cylinder 1 (upstream), the stagnation point is right at an angle of 0° and this is the highest Cp value of 1, after the stagnation point of the flow accelerates marked by decreasing Cp to 35° upper side and 325° lower side angle, this is due to the flow through favorable regions that are stream tube shaped the nozzle then increases its Cp to an angle of ± 55° upper side and an angle of 305° which is caused by the narrowing between the IDB with a circular cylinder 1 which causes blockage, consequently the flow momentum decreases. Then again accelerated to an 80 ° upper side angle and a 280° lower side angle caused by the momentum of the flow and the effect of wake from the IDB, which caused the shear layer to be released back to re-attachment on the surface of cylinder 1 which was marked with peak. Then the return flow follows the cylinder surface contour 1 which marked a pressure drop until the separation occurs at ± 115° upper side and ± 245° angle lower side.

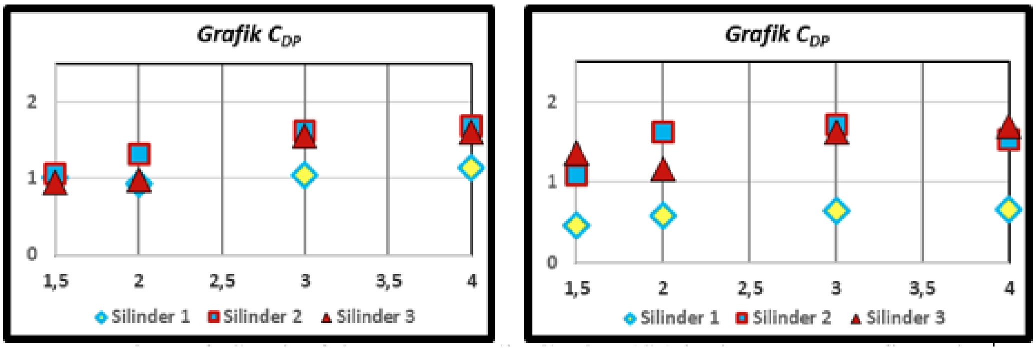
For cylinder 2 (top downstream) and cylinder 3 (downstream down) for transversal distance T/D=4, the pressure coefficient distribution has similarities both in the upper side and lower side positions. The similarity of the pressure distribution between the two cylinders is due to the absence of the influence of bistable effects. So that the flow across cylinder 2 and cylinder 3 is ordinary flow which is only affected by the separation of cylinder 1 (upstream). This effect of wake cylinder 1 causes a slight peak on both cylinders.

For cylinders 2 points the stagnation is at an angle of ± 355° the Cp value is 0.9, while for the cylinder 3 the stagnation point is at an angle of 0° and its Cp value is 1. For cylinder 2 after the attachment point at an angle of 0° and after the point stagnation for cylinder 3, the flow is accelerated which causes the pressure coefficient to drop to an extreme maximum at ± 65° at its Cp value of -2.5 for cylinder 1 and at ± 65° at its Cp value of -2.3 for cylinder 3 in the upper side position. Whereas in the lower side position the maximum velocity of flow occurs at ± 285° at its Cp value of 2,4 for cylinder 2 and at angle of ± 290° its Cp value is 2,3 for cylinder 3.

Then the flow on cylinder 2 and cylinder 3 both experienced a slowdown due to adverse pressure which is characterized by increasing pressure coefficient which causes the flow to no longer be able to fight adverse pressure and friction that occurs so that the separation is indicated by the coefficient of pressure starting steady at an angle of 90° for cylinder 2 and cylinder 3 in the upper side position and 265° for cylinder 2 and cylinder 3 on the lower side position, but the distribution of the pressure coefficient on cylinder 2 and the cylinder between the 90° -265° angle range also experiences a slow pressure coefficient - slowly to an angle of ± 175° the Cp value is -2.4 for cylinder 2 and at an angle of ± 175° the Cp value is -2.3.

3.3. Speed profile behind three circular cylinders arranged in stagger without IDB and with IDB 30°

The velocity profile that occurs behind the 3 circular cylinders arranged in a stagger shows a significant difference between the transverse distance variations of T/D 1.5 and 2 with the T/D 3 and 4 transversal distances (Figures 5a and 5b). At a distance of T/D = 1.5 the largest momentum deficit is indicated by the lowest U/Umaks value compared to the distance T/D = 2, 3 and 4 This is because the flow across the 1 (upstream) cylinder is aligned and returns about cylinder 2 (top downstream) and cylinder 3 (downstream down) and are still affected by wake. And the biggest momentum deficit occurs in cylinder position 2 and cylinder 3 while in cylinder 1 the momentum deficit is smaller. Whereas at a distance of T/D = 4 the momentum deficit is smaller, this is because the aligned flow and wake of cylinder 1 are not too large to affect cylinder 2 and cylinder 3, so the momentum deficit is smaller and even for cylinder 1 on the variation of the T/D 4 momentum deficit is very small with a U/Umaks value of 0.849 for variations without IDB and U/Umaks of 0.856 for variations with IDB.



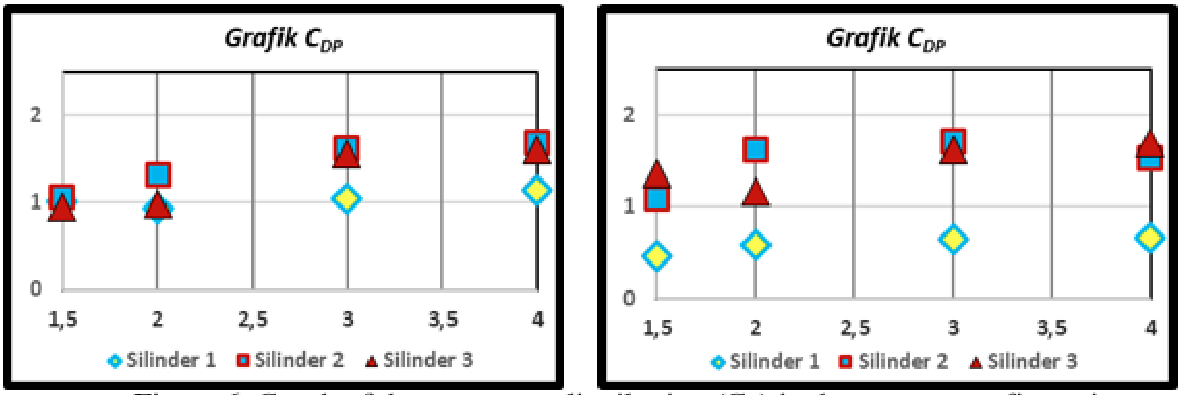
(a) (b)

Figure 5. Speed profile graph behind 3 circular cylinders, stagger configuration (a) With no IDB; (b) With IDB 30°

There is a difference between the results of the velocity profile distribution in the stagger configuration without IDB with a 30° IDB stagger configuration as shown in (Figure 5a and 5b), indicating that the momentum deficit that occurs for the distance T/D = 4 in the stagger configuration with IDB 30° far smaller than without IDB, this is because the flow of the disrupted body is repaired and re-attached to the cylinder contour 1 and the flow has slowed until the separation occurs, so the effect of the separation and wake of cylinder 1 is smaller than the stagger configuration without IDB for distance T/D = 4 which is marked by a larger U/Umaks that is 0.856 whereas at a distance of T/D=1.5 and 2 the momentum deficit is almost similar to the position of cylinder 2 and cylinder 3 and only on cylinder 1 there is a difference in momentum effect.

3.4. Analysis of Distribution of Drag Pressure (CDP) Coefficients on three Stagger Circular Cylinders without IDB and with 30° IDB

The pressure drag coefficient distribution for cylinder 1 in the stagger configuration without IDB has the lowest value compared to cylinder 2 and cylinder 3 as shown in (figure 6a), this occurs in variations in transversal distances between cylinders (T/D) = 2, 3 and 4, but at (T/D) = 1 the value is greater than cylinder 3 and for the lowest C_{DP} value is 0.93 is in the variation of distance (T/D) = 2. While for cylinder 2 the pressure drags coefficient, distribution has the highest value for all variations of transversal distance (T/D) between cylinders, as well as for cylinder 3, the distribution value of the pressure drag coefficient is higher than cylinder 1 except for distance (T/D) = 1.



(a) (b)

Figure 6. Graph of drag pressure distribution (C_{DP}) in the stagger configuration
(a) Without IDB; (b) IDB 30°

The drag pressure coefficient (C_{DP}) distribution in the stagger configuration with IDB 30° is almost the same as C_{DP} without IDB, the lowest C_{DP} value remains on cylinder 1 for all transversal distance variations (T/D) = 1.5 to 4, compared to cylinder 2 and cylinder 3 as shown in (figure 6), but for cylinder 2 and cylinder 3 it is more volatile, namely in variation (T/D) = 1.5 C_{DP} value for cylinder 2 lower while in variation (T/D) = 2 the value of C_{DP} cylinder 3 is much lower than that of cylinder 2 and the variation in distance (T/D) = 3 and 4 C_{DP} values for cylinder 2 and cylinder 3 are almost close.

4. Conclusion

Based on the analyzes described above, there are several conclusions that can be taken as follows, there is a significant Cp difference between cylinder 2 and cylinder 3 at a distance of T/D = 1.5, this condition is caused by the effect of bistable effects (close range), while at a distance of T/D = 3 and 4, the Cp distribution is more stable. The use of IDB at position 30° can reduce pressure drag coefficient (C_{DP}) by 36-53% for cylinder 1 in all variations of distance T/D, while for cylinder 2 (upper downstream), the drag is higher for (T/D) = 1.5, 2 and 3 that is 3.2-22% and at (T/D) = 4 the drag force is reduced to 9% again. For cylinder 3 (downstream down) in the stagger configuration with IDB 30º, the drag is 4.8-44% higher for all distance variations (T/D) compared to the stagger configuration without IDB. On cylinders with IDB 30° boundary layer flow transition occurs faster so that the occurrence of the delay point separation, this is what reduces the pressure drag coefficient (C_{DP}).

5. Acknowledgment

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