

NUMERICAL ANALYSIS FOR 2D FLOW OVER DIFFERENT RATIO'S RECTANGULAR

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Received: October 23, 2019; Revised: March 15, 2020; Accepted: March 26, 2020

Abstract

A fundamental fluid mechanics problem is that fluid flow over the solid body's like a rectangular (square) cylinder, and it has been a popular research focus for many years. The simple two-dimensional solver implemented using a staggered structured mesh with used two models for analysis, one is viscous laminar for $Re \geq 40$, and another model is viscous K-epsilon (2 equation) for $50 \leq Re \leq 1,000$ where the blockage ratio is 0.01. For this simulation using FVM (Finite volume method) with a SIMPLE algorithm. Six different ratios rectangular cylinder used for finding the alliance between solid body's length and flow characteristic. Where the length and width ratio were $A/D = 0.25, 0.50, 1, 2, 3$, and 4. Numerical results for the generated bubble's width and length, the drag coefficient, velocity, and pressure reported. It observed that the generated bubble's width and length decreasing with the increasing cylinder length at the same Reynolds number ($3 \leq Re \leq 30$). The drag coefficient decreases proportionally with the increasing Reynolds number. After passed the stable to unstable critical Reynolds number for each ratio, the drag coefficient started to increase. At Reynolds number 300, the flow over $A/D = 0.25, 0.50$, and 1 is unstable That time the flow over $A/D = 2, 3$, and 4 is stable. It also observed that flow stability also depends on the ratios of the rectangular cylinder. The current prediction for the square cylinder is in a good covenant with the previous numerical and experimental study.

Keywords: Different ratio's model, Rectangular cylinder, Numerical analysis, 2D simulation, Viscous laminar, and Viscous K-epsilon model

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Introduction

The examination of the flow characteristic of the flow over a square cylinder is a significant and critical factor for engineering activity such as flow over vehicles, offshore facilities, affect airflow on structure, water flow effect on bridge's column, airflow effect on the lift, etc. Currently, many researchers have an interest in researching the flow over the solid body. Many experimental and numerical articles have about on this topic since 1927.

Fage and Johansen (1927) proclaimed by an experiment that the vortices longitudinal spacing decreases as the inclination of the plate decrease, and the speed for the vortices pass downstream increases with the plate decreases. That experiment's flow was periodic. The produced vortices were passing downstream with a frequency that increases with the inclination of the plate decreases. For the constant inclination, wind speed and frequency are proportional to each other. The two edges of the plate vorticity shed similar. This proportion falls gradually when the inclination is decreasing from 90°. Delany and Sorensen (1953) locate the rough variety of the drag coefficient for various Reynolds numbers for a few chambers. Nakaguchi (1968) revealed that the drag coefficient C_d shifts with the proportion of the chamber, where the flow re-attaches on the sidelong surfaces of the cylinder and that experiments were for high Reynolds number. Bearman and Trueman (1972) confirm that when the section depth is just over half the width, that time drag coefficient rises to nearly three, and the presence of the trailing-edge corners strongly influenced the flow around the sections. Okajima (1982) find by an experiment how strouhal numbers differ with the width-to-height proportion of the chambers in the stature Reynolds number. Laneville and Yong (1983) consider that the proximity of the segment bubble with a base size that creates a width-to-length proportion from the leading edge.

The vorticity contained at the underlying shear layer of the two-dimensional rectangular chamber. This vorticity appropriated contrastingly, as the fragment of the cylinders ends up being

longer. The scattering of this basic vorticity is accountable for the different territory of the vortex course of action. Davis *et al.* (1984) compared the numerical and experimental model and found that the form of upstream velocity profile ahead of the rectangle have important on the vortex shedding. Thus, in practical situations, the blockage ratio affects the x velocity, pressure, and drag coefficient-good agreement founded between numerical and experimental results for $Re \leq 1,000$. Nakamura *et al.* (1991) proposed that the effects of expanded blending and debilitated standard vortex shedding rely upon the profundity to length proportion of a rectangular cylinder. Experiments performed by Ohya (1994) on two values of the blockage ratios flow over a rectangular cylinder. For depth-to-width ratio 0.5, the critical flow pattern begins to appear intermittently. At around depth-to-width ratio 0.6, a stable critical flow pattern established. Initially, the flow around a cylinder changes steps by step with expanding profundity to width proportions. However, when proportions achieve a transitional range around 0.5, there was an unexpected change in the flow design for the abrupt change in the flow design around the cylinder. The most effective numerical study focused on the time dependable flow, which is known as unsteady flow. Davis and Moore (1982); Nagano *et al.* (1982); Okajima (1990); Okajima *et al.* (1993); Minewitsch *et al.* (1994); Sohankar *et al.* (1998); Singh *et al.* (2009), and Kumar and Ray (2015) studied on unsteady flow over a square cylinder. In this study, we investigated the analysis of incompressible steady flow over different ratios rectangular cylinder. Some research discussed both steady and unsteady flow over a square cylinder. Breuer *et al.* (2000) investigated two different numerical techniques, one was lattice- Boltzmann automata (LBA), and another one was the finite-volume method (FVM). Lamura *et al.* (2001); Gupta *et al.* (2003); Sharma and Eswaran (2004), and Meliga *et al.* (2014) also studied flow over a square cylinder. The most effective result for steady flow over a square cylinder at low

Reynolds number given by Sen *et al.* (2011). In, that study blockage ratio 0.01 used to avoid effect on flow by outer boundary, and he discussed the separation of the bubble, bubble length, bubble width, velocity, and drag coefficient. The separation of the bubble approximately linearly with the Reynolds number. For the non-dimensional vortex shedding frequency and r.m.s values for aerodynamics, increase monotonically with the increasing Reynolds number.

Physical Model and the Numerical Method

Governing Equation

In the incompressible two-dimensional flow over a rectangular cylinder, the fluid passed the channel forming a fixed speed profile at a fixed temperature. For the low Reynolds number, the flow can believe to be two-dimensional and steady. Here no flow happens in the z coordinate, and no flow variable depends upon z bearing, i.e., $\frac{\partial x}{\partial z} = 0$ for all factors x. The governing equation for this problem is the 2D flow. Navier-Stokes equation, the continuity equation, and the momentum equation given below:

$$\nabla(\rho V) = 0 \quad (1)$$

$$\nabla(\rho V u) = \nabla \cdot (\mu \nabla u) - \nabla p \cdot i + S u \quad (2)$$

$$\nabla(\rho V v) = \nabla \cdot (\mu \nabla v) - \nabla p \cdot j + S v \quad (3)$$

Here ∇ is the Divergence operator, ρ is the fluid density, V is the volume, μ is the diffusion constant, $p \cdot i$ is the scalar pressure on the x-direction unit vector, and $p \cdot j$ is the scalar pressure on the y-direction unit vector. The source terms $S u$ and $S v$ for the Equations no (2) and (3) Newtonian fluid can write as:

$$S u = f u + \frac{\partial}{\partial x} \left(\mu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu \frac{\partial v}{\partial x} \right) - \frac{2}{3} \frac{\partial}{\partial x} (\mu \nabla \cdot V) \quad (4)$$

$$S v = f v + \frac{\partial}{\partial y} \left(\mu \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial x} \left(\mu \frac{\partial u}{\partial y} \right) - \frac{2}{3} \frac{\partial}{\partial y} (\mu \nabla \cdot V) \quad (5)$$

We have a general transport equation for the transport of any scalar ϕ , which we can write as:

$$\frac{\partial}{\partial t} (\rho \phi) + \nabla \cdot (\rho V \phi) = \nabla \cdot (\Gamma \nabla \phi) + S \quad (6)$$

The general transport equation reduces to convection term balanced by diffusion and source terms as follows:

$$\nabla \cdot (\rho V \phi) = \nabla \cdot (\Gamma \nabla \phi) + S \quad (7)$$

Comparing the u-momentum equation 2 to general transport equation 7 we get $\phi = u$, $\Gamma = \mu$, and $S = S u - \frac{\partial p}{\partial x}$. Further, in the present case, viscosity (μ) and density (ρ) of the fluid are constant, and assuming that nobody forces acting on the flow domain, the source terms $S u$ and $S v$ are zero. So that the continuity equation for the incompressible fluid $\nabla \cdot V = 0$ in Equations 4 and 5.

Problem Setup and Boundary Condition

The edge length of this rectangular cylinder was D , which set in a computational space with the outside boundary as a rectangular shown in Figure 1. The start of the cartesian orchestrate system matches with the point of convergence of the chamber and the fluid flow left to the right side and the positive x-axis in a downstream way. The air utilized to maintain consistent density. The partition between the sidewalls H , being $100D$ gives a blockage of 0.01. The separations of the upstream and downstream limits from the cause of the organizing framework are signified by L_u and L_d separately. For the present investigation, $L_u = 80D$ and $L_d = 100D$ were adequately enormous to create arrangements free from the

impacts of the delta and boundary condition. The Reynolds number $Re (= \frac{\rho v l}{\mu})$ relies upon the edge length and free-stream speed.

The square cylinder with side D , additionally the non-denationalizing length scale, was presented to a wholly created (parabolic for a Newtonian fluid) velocity field with the most extreme velocity of U_{max} at the cylinder inlet. The computational space facilitates the definition and boundary conditions used in the present examination given in Figures 1 and 2. Considering the mesh number must be low as possible as we could recognize for compelling figuring. Figure 2(a) exhibits the mesh plan for the square cylinder. The typical mesh style is employing for the cylinder model is to settle it in a square zone around numerous occasions greater than itself shown in Figure 2(b). The stature of the first boundary layer picked to be 0.05, and an improvement factor is 1.1. In this study applying the non-uniform multi-rectangular structured mesh shown in Figure 2(a) with the number of elements 304737 and the number of nodes 303552 separately.

The mesh consists of nine blocks. A central square containing the chamber and eight neighboring rectangular cylinder includes a cartesian non-uniform organized mesh with different uniform expansion in segment sizes along the promising direction. The top and base squares are indistinguishable portrayals of each other. The winding grid lines in the central square keep up uniform isolating except for in the advance neighborhoods of the sharp corners. The effects of edges to decrease, the node by the sharp edges on either side arranged at a little x or y expel from the corners. Here for estimation using FVM procedure with no-slip stationary divider boundary condition expecting speed $v = 0$ at the wall.

Simulating Results and Analysis

Validation and Convergence Condition

The numerical solution procedure used here benchmarked with the standard results for Newtonian fluid flow across a square cylinder.

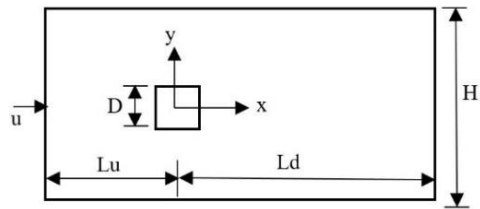


Figure 1. Quandary operation for fluid flow over a square Cylinder

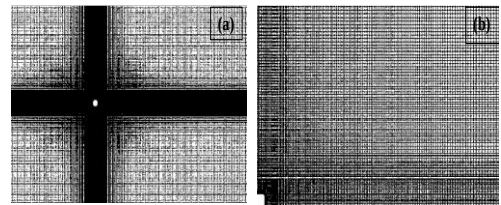


Figure 2. a) Grid of the entire computational domain; b) Magnified view near the square cylinder

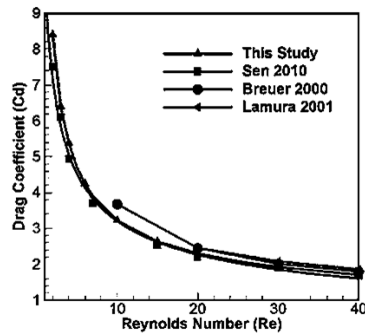


Figure 3. Comparison of drag coefficient with previous studies

The solution method based on the SIMPLE FVM algorithm. For the mesh specific ANSYS ICEM CFD was used, which is popular proprietary software for generating the mesh. As a solver used ANSYS FLUENT, which is a powerful computational fluid dynamics software. For post-processing simulation used Tec-plot 360. Figures 3 and 4 show the comparison with the earlier numerical and experimental studies for the square cylinder at Reynolds number $0 \leq Re \leq 35$. The case

validated against results Breuer *et al.* (2000); Lamura *et al.* (2001), and Sen *et al.* (2011). For this geometry, the degree of the spatial area was kept the same in every one of the cases ($Lu = 80D$, $Ld = 100D$, and $B = 0.01$). In this issue utilizing absolute criteria for convergence. For the continuity equation, the convergence criteria were 0.00001, for x velocity convergence condition used 0.00001, and for Y speed, it was 0.00001. The present outcome for the drag coefficient is in close concurrence with Sen *et al.* (2011) The Figure likewise delights the general strength of the drag coefficient over its thick partner appeared in Figure 3. The drag coefficient of this study found a satisfactory result and almost similar to the recent numerical and experimental studies. At Reynolds, 10 and 15 identical drag coefficients found with Sen *et al.* (2011). Table 1 represents the relative error of the result of the present study and those references. Figure 4 shows the improvement of the bubble partition whenever $Re = 1.5, 5, 24$, and 40. The current expectation of streamline and the bubble separation has remarkable concurrence with those revealed by Sen *et al.* (2011).

Table 1. The relative error of the result of the present study and those references

Studies	Cd at Re 10	Cd at Re 20	Cd at Re 30	Cd at Re 40
This Study	3.221	2.305	1.928	1.709
Sen 2010	3.216	2.26	1.88	1.68
Relative error	0.16%	1.95%	2.45%	1.7%

Calculating Results for different ratio's Rectangular Cylinder

Two-dimensional numerical analysis for incompressible flow over different ratio's rectangular cylinder where $A/D = 0.25, 0.50, 1, 2, 3$, and 4 flow characteristics studied for various Reynolds Number ($0 \leq Re \leq 1,000$). The blockage ratio kept very low ($B = 0.01$) to avoid outside boundary effects. The laminar model was used to measure bubble length and bubble width, where the Reynolds number $0 \leq Re \leq 35$. With the increasing length of the cylinder, the bubble length is approximate linearly decreasing. With the decreasing cylinder

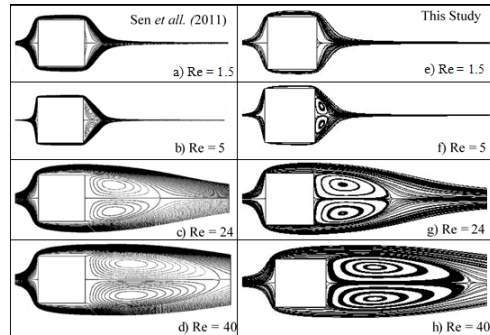


Figure 4. Comparison of streamline; a), b), c), and d) are the streamlined result for Sen *et al.* (2011); e), f), g), and h) are this study streamline results

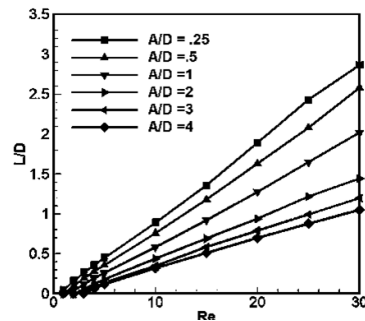


Figure 5. Comparison of bubble length with different ratios rectangular cylinder

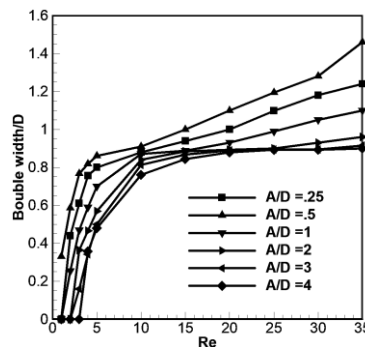


Figure 6. Comparison of bubble width with different ratios rectangular cylinder

length, the bubble length is approximate linearly increasing at the same Reynolds number, which shown in Figure 5. Figure 6 shows the comparison of the bubble width

for different ratios rectangular cylinder at Reynolds number up to 35, and this characteristic is proportional with the bubbles length characteristics.

For the compares drag coefficient (C_d), velocity, pressure, and streamline diagram using Viscous K-epsilon (2 equations) and counting Reynolds number $1 \leq Re \leq 1,000$. Figure 7 shows the Comparison Drag Coefficient with different Ratios Rectangular cylinder at $1 \leq Re \leq 1,000$. For calculating C_d

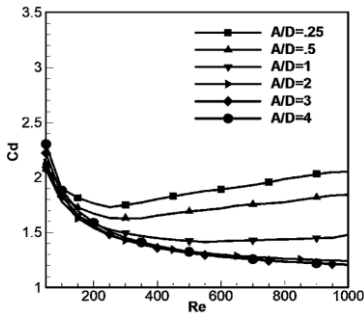


Figure 7. Comparison of Drag Coefficient with different ratios rectangular cylinder at $50 \leq Re \leq 1,000$

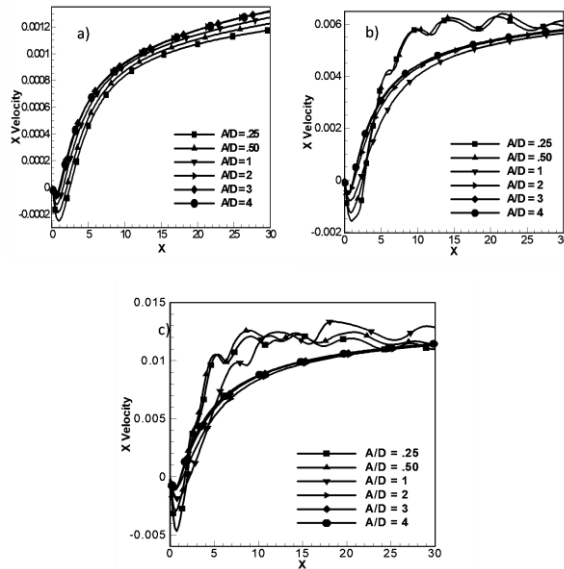


Figure 8. Comparison of u velocity distribution for different ratios rectangular cylinder; a) X Velocity distribution at $Re = 100$, b) X Velocity distribution at $Re = 500$, and c) X Velocity distribution at $Re = 1,000$

using $Cd = \frac{D}{\rho v^2 A}$. Drag coefficient decreases proportionally with the increasing Reynolds number up to reach the critical Reynolds number for stable to unstable. After passed the stable to unstable critical Reynolds number for each ratio, the drag coefficient started to increase. We found that the significant Reynolds number is different for different ratios rectangular. At Reynolds, number 300, the flow over $A/D = 0.25, 0.50$, and 1 is unstable That time, the flow over $A/D = 2, 3$, and 4 was stable. When $Re \geq 300$ and the drag coefficient Cd was increasing for $A/D = 0.25, 0.5$, and 1 , but there were a reverse characteristic shows for the $A/D = 2, 3$, and 4 , literature research reveals none experimental study about this characteristic. Drag depends legitimately on the mass of the stream going past the bluff-body. In fluid elements, The drag in some cases called air obstruction, a rubbing, or fluid opposition, another grinding or fluid contact, is a power acting inverse to the general movement.

At $Re = 100$, all ratios centerline velocity curve smooth, and the flow is stable shown in Figure 8(a). At $Re = 500$, $A/D = 4, 3, 2$, and 1

was stable, and $A/D = 0.50$ and 0.25 was unstable shown at Figure 8(b), and for the $Re = 1,000$, $A/D = 4, 3$, and 2 was stable and $A/D = 1, 0.50$, and 0.25 is unstable shown at Figure 8(c). Figure 9 also shows the mean u velocity contour distribution for $Re = 1,000$ for all ratios. The shapes demonstrate that the age of turbulent kinetic energy was identical with the shear in the flow emerging from the cylinder. The most significant estimation of the turbulent kinetic energy around the $A/D = 0.25$ cylinders turns out to be little contrasted and that for other cylinders. The

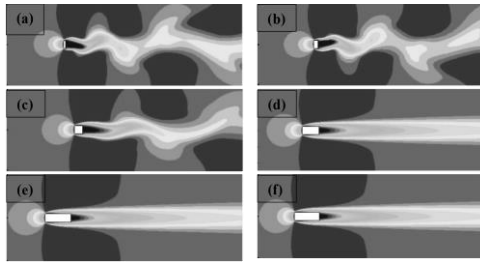


Figure 9. Velocity profile of all ratio's rectangular cylinder at $Re = 1,000$; a) u velocity profile for ratio $A/D = 0.25$, b) u velocity profile for ratio $A/D = 0.5$, c) u velocity profile for ratio $A/D = 1$, d) u velocity profile for ratio $A/D = 2$, e) u velocity profile for ratio $A/D = 3$, and f) u velocity profile for ratio $A/D = 4$

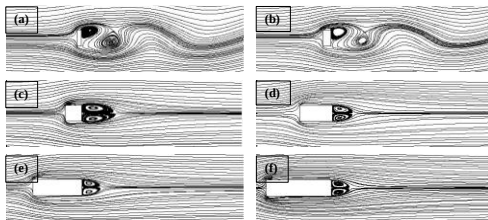


Figure 10. Streamline diagram shows the bubble separation at Reynolds number 500; a) Streamline for ratio $A/D = 0.25$, b) Streamline for ratio $A/D = 0.5$, c) Streamline for ratio $A/D = 1$, d) Streamline for ratio $A/D = 2$, e) Streamline for ratio $A/D = 3$, and f) Streamline for ratio $A/D = 4$

flow stability is also dependent on the bluff body length.

Streamline diagram and the development of the bubble separation at $Re = 500$ for all ratios rectangular cylinder shown in Figure 10. It observed that with the rising bluff body length, the Reynolds number for unstable flow was also increasing. In the next study, we will try to find out the critical Reynolds number for every ratio for the stable to unstable flow and try to find out the relationship between bluff body length and critical Reynolds number.

Pressure dispersal is a critical factor for the examination of flow over a rectangular cylinder pressure characterized as a typical power applied by fluid for every unit zone. Pressure changes similarly to the vortex's development in the locale of the bodies. Stream disengages, on the other hand, around symmetrical bodies with sharp corners, for instance, the fundamental edge of a rectangular portion to shape vortices around the load. This condition is particularly critical in-stream, including fluid and structure association, for instance, the flow around a tall structure or suspension interface. Regardless of the way pressure incited, power does not impact the diversion on a fixed block beyond a shadow of a doubt. Vortex improvement and development start control of the bodies enclosed by the flow. A vortex makes a negative weight suction locale touching the surface where it propels. Appropriately, the examination of weight scattering is enormous in the analysis of the streamlined powers around a structure. The weight scattering near the outside of the cylinder, stream vitality was low as a direct result of gooeey effects. These lines were tricky to the movements of the pressure edge. Figure 11 demonstrates a commonplace pressure circulation, and the region of these motivations behind division depends upon the nuances of the associated limit layer and the pulling back shear layers. Figure 12 demonstrates a regular pressure conveyance plot along to the centerlines for the stream around all proportions rectangular cylinder For $Re = 1,000$. For $A/D = 0.25, 0.5$, and 1 , more pressure created at the front upstream and downstream corner. On the other hand, for

$A/D = 2, 3$, and 4 , pressure distribution around the bluff body was smooth.

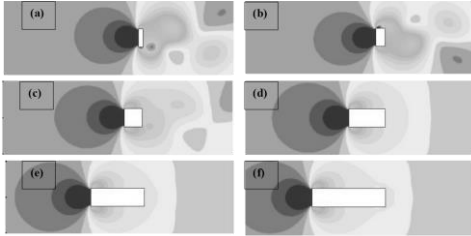


Figure 11. Flow past different ratios rectangular cylinder pressure distribution at Reynolds number 1000; a) Pressure distribution at $A/D = 0.25$, b) Pressure distribution at $A/D = 0.5$, c) Pressure distribution at $A/D = 1$, d) Pressure distribution at $A/D = 2$, e) Pressure distribution at $A/D = 3$, and f) Pressure distribution at $A/D = 4$

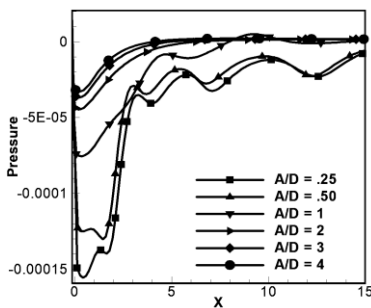


Figure 12. Comparison of pressure P distribution along with the wake centerline flow past different ratios rectangular cylinder

Conclusions

This study has successfully applied two model viscous laminar for $Re \geq 40$, and another Model is viscous K-epsilon (2 equations) for $50 \leq Re \leq 1,000$. A stabilized FVM method used to predict two-dimensional numerical analysis of incompressible flow over different ratio's rectangular cylinder at blockage ratio 0.01. Several conclusions obtained as follows:

1. Generated the bubble's width, and the length was decreasing with the increasing cylinder length at the same Reynolds number ($3 \leq Re \leq 40$).

2. The drag coefficient decreases proportionally with the increasing Reynolds number. After passed the stable to unstable critical Reynolds number for each ratio, the drag coefficient started to increase.

3. At Reynolds, number 300, the flow over $A/D = 0.25, 0.50$, and 1 is unstable. That time the flow over $A/D = 2, 3$ and 4 is stable. It also observed that flow stability also depends on the ratios of the rectangular cylinder.

4. For $A/D = 0.25, 0.5$ and 1 , more pressure created at the front upstream and downstream corner. On the other hand, for $A/D = 2, 3$, and 4 , pressure distribution around the bluff body was smooth.

Finally, we can consider that at same Reynolds number flow over different ratios rectangular shows different characteristic and the critical Reynolds number for stable to unstable flow also depend on the ratios of the rectangular.

Acknowledgments

The authors would like to express gratitude to the Government of the Republic of China for providing the funds for this research. This work supported by the National Natural Science Foundation of China (51536008, 51579224); Zhejiang Key Research and Development Program (2018C03046).

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