Journal of Advanced Research in Applied Sciences and Engineering Technology 30, Issue 2 (2023) 216-224

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Numerical Study of Heat Transfer and Fluid Flow over Circular Cylinders in 2D Cross Flow

Sarah Rabee Nashee[1,*], Haiyder Minin Hmood[2]

[1] Department of Mechanical Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, 64001, Iraq
[2] Department of Scientific Affairs and Postgraduate Studies, College of Education for Human Sciences, University of Thi-Qar, Thi-Qar, 64001, Iraq

ARTICLE INFO

Article history:
Received 5 January 2023
Received in revised form 28 February 2023
Accepted 28 March 2023
Available online 20 April 2023

Keywords:
Heat Transfer; Computational Fluid Dynamics; Nusselt Number; Circular Cylinder

ABSTRACT

Among the many experiments Which deals with the study of the characteristics of flow, a numerical study of flow air (Pr=0.71) crosses a circular cylinder is conducted. Variations in flow and thermal characteristics such as average Nusselt number, local pressure coefficient and drag coefficient are presented around the cylinders for Reynold numbers ranging from 100 to 5000 by solving the incompressible two-dimensional unsteady Navier-Stokes and energy equations. Commercial software package FLUENT 19 is applied to solve the equations. The diameter of the circle is D = 20 mm, the width is 20 times the diameter of the cylinder. The results obtained are compared with data of previous study for Nusselt Number values showed acceptable agreement. The results of the drag coefficient confirm a noticeable decrease in the transition from low values of Reynolds numbers to the high values.

1. Introduction

This review is an important area in investigations to know the behavior of fluid flow and the heat transfer. It is the basis for many thermal applications, such as bridge piers, submarines, overhead cables etc. Despite the normal and simple geometry of the cylinder, it remains important and interesting physical phenomenon. A series of tests were performed by Igarashi [1,2] at high values of Reynolds Numbers to find the results of drag coefficients and pressure around two circular cylinders. The impacts of changing the longitudinal distance between cylinders and their diameters were studied. Kawamura and Kuwahara [3] show intrest in this aspect and studied the characteristics of flow around a circular cylinder with roughness and smooth surface for a turbulence flow (Re= 10^3-10^5). The results show that the drag crisis phenomenon on surface roughness for the critical value of Reynolds number was small when compared with that of the smooth cylinder. Similarly, Mehrabian [4] conducted an investigation by applied forced convection to exam the rate of cooling of a copper cylindrical. Also, investigation has been done to measure the heat transfer characteristics of the system. Sumer [5] have investigated this problem for a wide range of Reynolds numbers 40 < Re <

* *Corresponding author.*
E-mail address: Sara.rabee@utq.edu.iq

https://doi.org/10.37934/araset.30.2.216224

200, by studied the forming of the laminar vortex shedding in the wake of the cylinder. Also, by using a numerical analysis with turbulent flow of Re range 2.3×10^3 to 4×10^5 kolos [6] performed tests of flow Around a Cylinder. Yuce *et al.,* [7], conducted investigation to test 2D laminar flow around circular cylinder for (Re=2) and turbulent flow for (Re=4×10^6) and performed a comparison with square and triangle. Rao [8] tested numerically the flow over a circular cylinder for Reynolds numbers ≤ 200 for 2D flow, where investigated the vortexes that forming after the circle during the flow. Rahman *et al.,* [9], investigated the behavior of 2D flow by test the wake zone downstream the circular turbulent and laminar, by computing the drag and pressure coefficients for the range of Reynolds numbers (Re=10^3 to 3.9×10^3) . Furthermore, Jibran *et al.,* [10] completed an investigation deals with the flow characteristics across circular cylinder as single circular cylinder and arrays of cylinders by using different Reynolds number changed from 40 to 10000. In regard to the current study, 2d flow across single circular cylinder with various values of Reynolds numbers ranging from 100 to 5000 is studied numerically with diameter of circular cylinder D = 20mm. The study investigates the behavior of the flow across the circular cylinder by testing the Nusellt number with various Reynolds number. In addition, drag coefficient and Local pressure coefficient is tested.

2. Computational Methods

2.1 Model Description

A 2D analysis test is conducted as the length of the cylinder is much larger than its diameter, as clarify in Figure 1. The diameter of the circle is D =20mm. It is imposed that the distance from inlet to the origin is 20D. The width is kept much larger (25 times) than the diameter. The fluid was assumed to be air at (293 K), where the density was ρ = 1.2 (kg/m ^{3}).

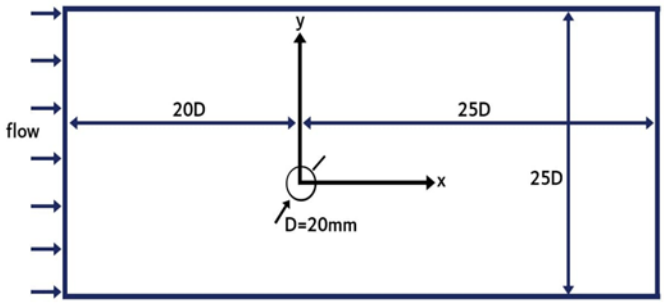


Fig. 1. Computational domain

2.2 Governing Equations

The actual geometrical size with the test model was created employing ANSYS-19. All the equations involved in the system are solved. These governing equations equation of continuity [11], conservation of momentum equations and energy equation [12] are:

Equation of continuity:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

x component of conservation of momentum:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \qquad (2)$$

y component of conservation of momentum:

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \quad (3)$$

Energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

where v,u : dimensionless velocity in x,y directions. The inlet velocity was found by the following formulae by using Reynolds number (Re) as a basis:

$$Re=\rho u_{avg.}D_h/\mu \quad (5)$$

The avarage Nusselt number is introduced as follows [13]:

$$Nu=\frac{h\,.D_h}{k} \quad (6)$$

2.3 Meshing and Grid Independency

An unstructured mesh was produced for the geometry modeled where the mesh is fine near the circular cylinder. Figure 2 focuses on the mesh in the proximity of the circular cylinder. The density of mesh is preserved intensive near the cylinder for resolving the boundary layer in accurate manner. The featured points of the mesh are known as nodes.

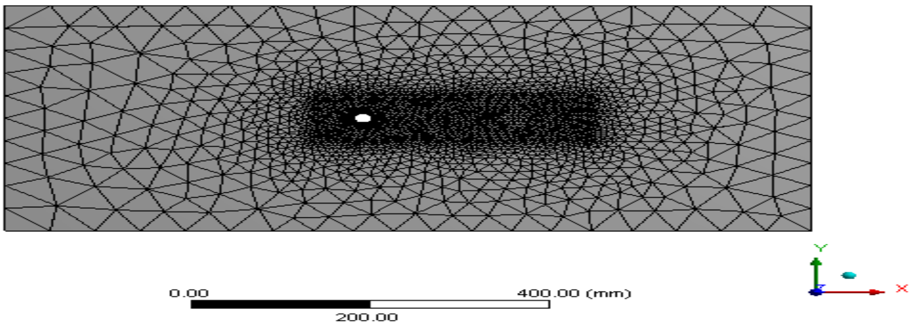


Fig. 2. Meshing near the cylinder and the domain

In order to gain accurate and reliable results, it is essential to use accurately the grid number. For that purpose, the test of grid independency was executed with respect to the drag coefficient. Four different meshes were generated, Mesh 1, Mesh 2, Mesh 3 and Mesh 4. Table 1 shows the meshes and corresponding numbers of elements employed in this investigation at Re= 100. Mesh 4 was chosen for the work. With medium smoothing and defeature size =0.25mm.

Table 1
Effect of Mesh elements on Average Nusselt Number and drag coefficient at Re = 100

Case	Mesh elements	Nu	The deviation	C_d	The deviation
Mesh 1	685491	7.846	-	0.9547	-
Mesh 2	695895	9.233	0.1502	1.4977	0.362
Mesh 3	703525	11.167	0.1731	2.0065	0.255
Mesh 4	704364	11.483	0.0275	2.1989	0.09

2.4 Boundary Conditions

Basically, The cylinder surface is no-slip wall and the lower and upper boundaries are free slip walls. In 2-D simulation, symmetry boundary conditions are utilized on the lateral planes of the domain of fluid, which sets the gradient of pressure normal to the plane and also velocity components, to (zero). Gravity is negligible.

3. Results and Discussions

In Figure 3, the differences of Nusselt number values along the cylinder is offered in comparison with the gained results of Krall and Eckert [13]. The results of Nusselt number have been extracted for Reynolds numbers 100 and 1000. The deviation between the results is 11%. The mismatch of results between the current research and comparative research is due to the difference in dimensional values and parameters. Furthermore, Krall and Eckert preserved the same boundary condition of uniform wall temperature and no slip on the cylinder as is achieved in the current study.

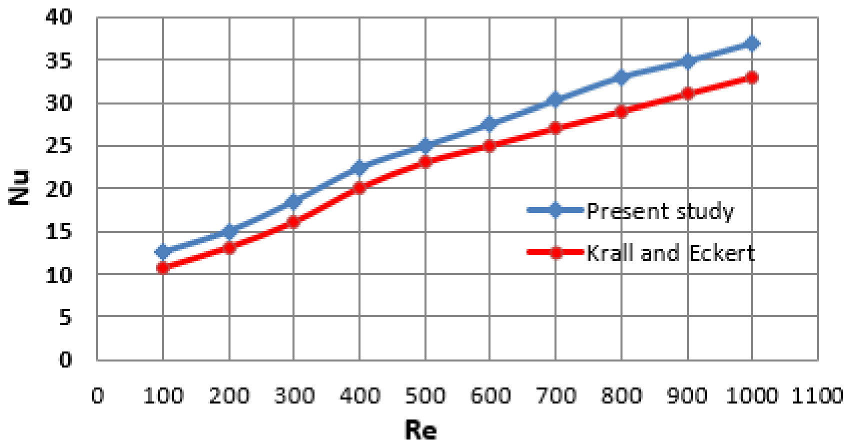


Fig. 3. Comparison Nusellt number results of the current study and Krall and Eckert [14]

As regard to local Nusselt number along the cylinder, a comparison has been performed between the present study and the results of Krall and Eckert [14] for Reynolds number 100. As display in Figure 4. Ones again the obtained results of the comparison give a very good agreement. The deviation between the results is 8 %. In the graphs presented, the values obtained by the present study are slightly higher than Krall and Eckert [14].

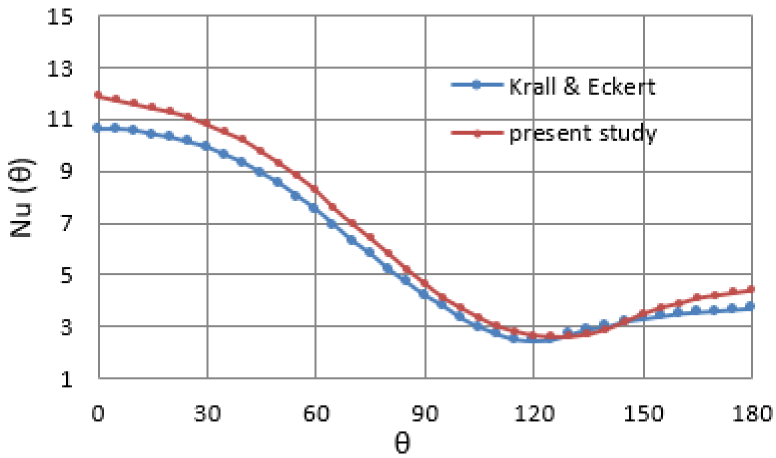


Fig. 4. Comparison of local Nusellt number of the current study and Krall and Eckert [14] at Re=100

Figure 5 show the variation of the averaged drag coefficient with Re. in a whole, the values of C_d display the expected inverse dependence on Reynold numbers values this due to the forming of the circulation zones that are created at the obstacles and make a negative drag coefficient.

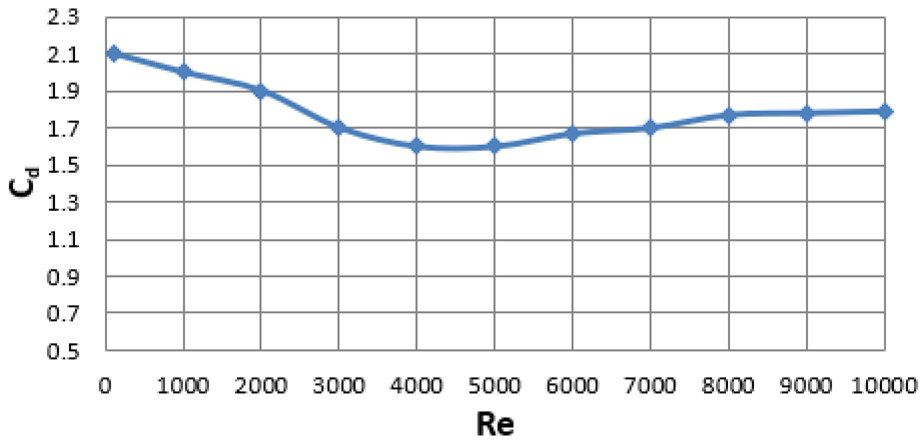


Fig. 5. Variation of drag coefficient with Reynolds number

In addition, the analytical results of local values of pressure coefficient along the cylinder's surface have been obtained. Figure 6 display the pressure distributions at Reynolds number of 100. A remarkable variant in pressure distribution around the cylinder it can be noticed. It obviously observes that the cylinder's front face is exerted to a greater pressure. This can be interpreted according to the slowdown of the flow the front face of the cylinder and become stagnation region. After that, the flow accelerated at the lower and upper sides of the cylinder create a drop in pressure. the surface pressure in the separated zone is approximately remains constant.

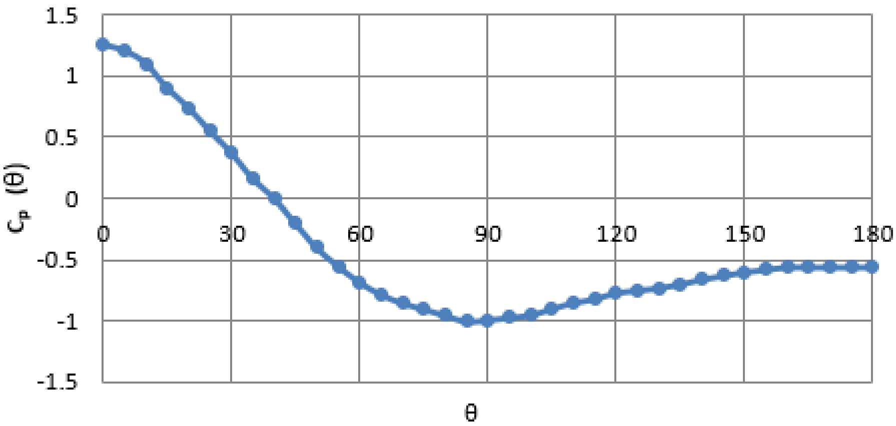


Fig. 6. Variation of C_p (θ) at Re=100

For Reynold number (Re) = 100, regarding the mean variables, mean drag coefficient, which is acquired by considering the period of the drag coefficients and as can be notice in Figure 7, due to the two-dimensional simulation, the drag coefficients oscillate in an irregular manner and with larger amplitude. The drag coefficient varies randomly. This can be caused in unsteady regions of the flow field.

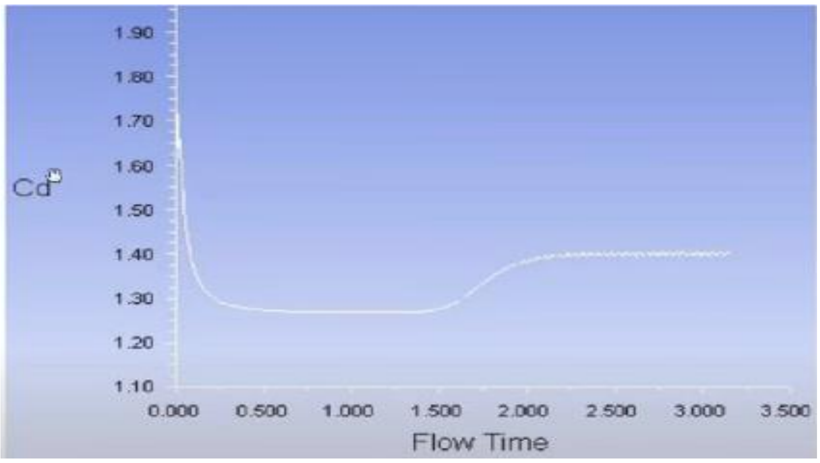
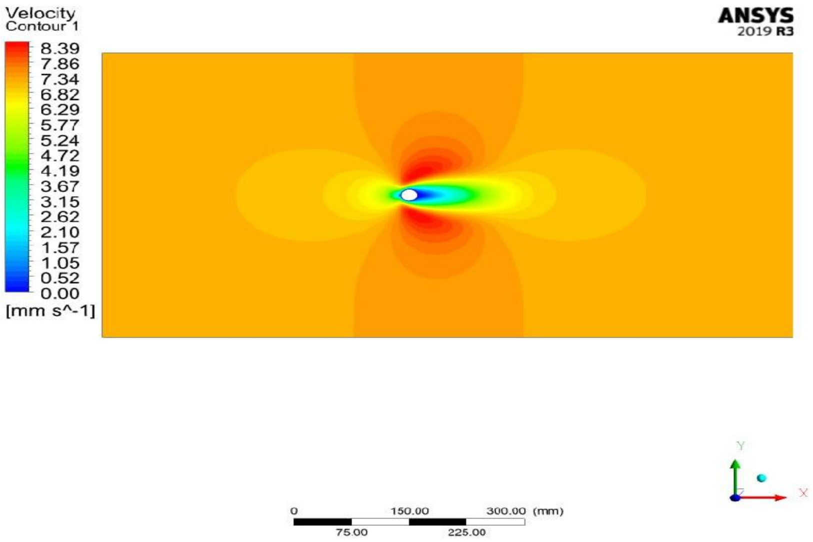
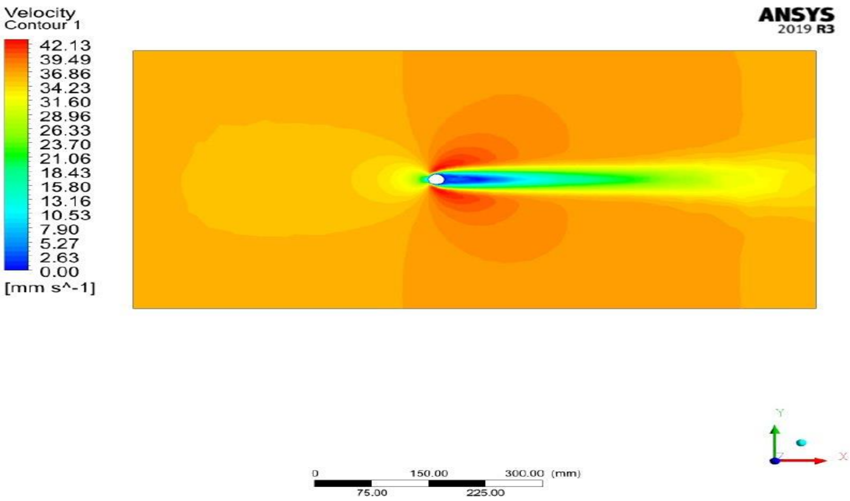


Fig. 7. Time history of the drag coefficients at Re =100

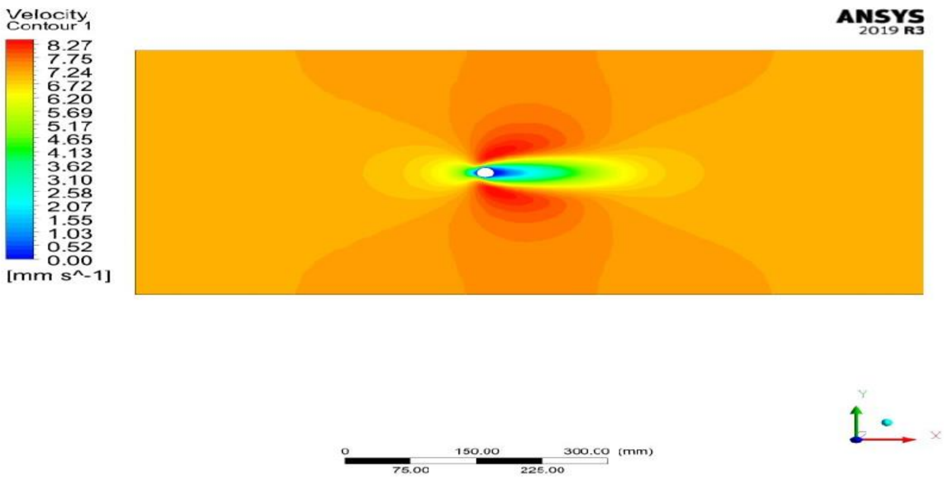
It is visibly that in Figure 8 the velocity contour for various Re. For the Re = 100 flow is organized and weak as observed. At higher Re values, the separated shear layer becomes smaller and unstable vortices form resulting to this instability. The high velocities occur at the lower and upper side are showed by red counters on the circular cylinder. In addition, the blue contours that shown at the front and rearward represent the decreasing in velocity contours. the separation of boundary layers creates at an angle about 75°. This becomes clear with Re increasing.


Velocity
Contour 1
8.39
7.86
7.34
6.82
6.29
5.77
5.24
4.72
4.19
3.67
3.15
2.62
2.10
1.57
1.05
0.52
0.00
[mm s^-1]
ANSYS
2019 R3
0
150.00
300.00 (mm)
75.00
225.00
Y
X

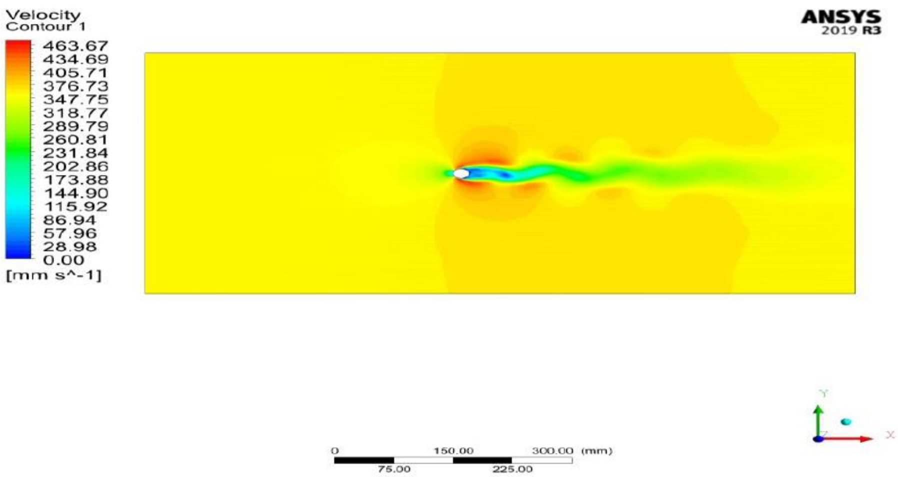
(a)


Velocity
Contour 1
42.13
39.49
36.86
34.23
31.60
28.96
26.33
23.70
21.06
18.43
15.80
13.16
10.53
7.90
5.27
2.63
0.00
[mm s^-1]
ANSYS
2019 R3
0
150.00
300.00 (mm)
75.00
225.00
Y
X

(b)


Velocity
Contour 1
8.27
7.75
7.24
6.72
6.20
5.69
5.17
4.65
4.13
3.62
3.10
2.58
2.07
1.55
1.03
0.52
0.00
[mm s^-1]
ANSYS
2019 R3
0
150.00
300.00 (mm)
75.00
225.00
Y
X

(c)



(d)

Fig. 8. the velocity contour 2-D simulation (a) Re=100 (b) Re=500 (c) Re=1000 (d) Re=5000

4. Conclusion

Numerical investigation has been conducted to analyze flow characteristics past a single cylinder for various Reynolds numbers. It can be obtained the following conclusions from the results that:

i. As regard pressure distribution on the cylinder surface, the cylinder's front face is exerted to a maximum pressure. The lower and upper sides of the tested cylinder make a drop in pressure.
ii. The gained results were found to be in very good agreement with earlier experiments by comparison the results of average Nusellt number and local Nusellt number.
iii. The high velocities give more circulation around the cylinder and this led to create vortices Thus, the heat transfer increases.

References

[1] Iragashi, T. "Characteristics of the flow around two circular cylinders arranged in tandem." *Bulletin of JSME* 24 (1981): 323-331. https://doi.org/10.1299/jsme1958.24.323
[2] IGARASHI, Tamotsu. "Characteristics of a flow around two circular cylinders of different diameters arranged in tandem." *Bulletin of JSME* 25, no. 201 (1982): 349-357. https://doi.org/10.1299/jsme1958.25.349
[3] Kawamura, Tetuya, and Kunio Kuwahara. "Computation of high Reynolds number flow around a circular cylinder with surface roughness." In *22nd Aerospace Sciences Meeting*, p. 340. 1984. https://doi.org/10.2514/6.1984-340
[4] Mehrabian, M. A. "Heat transfer and pressure drop characteristics of cross flow of air over a circular tube in isolation and/or in a tube bank." *Arabian Journal for Science and Engineering* 32, no. 2 B (2007): 365-376.
[5] Sumer, B. Mutlu. *Hydrodynamics around cylindrical strucures*. Vol. 26. World scientific, 2006. https://doi.org/10.1142/3316
[6] Kološ, Ivan, Vladimíra Michalcová, and Lenka Lausová. "Numerical analysis of flow around a cylinder in critical and subcritical regime." *Sustainability* 13, no. 4 (2021): 2048. https://doi.org/10.3390/su13042048
[7] Yuce, Mehmet Ishak, and Dalshad Ahmed Kareem. "A numerical analysis of fluid flow around circular and square cylinders." *Journal-American Water Works Association* 108, no. 10 (2016): E546-E554. https://doi.org/10.5942/jawwa.2016.108.0141
[8] Rao, Anirudh, Mark Christopher Thompson, Thomas Leweke, and Kerry Hourigan. "The flow past a circular cylinder translating at different heights above a wall." *Journal of Fluids and Structures* 41 (2013): 9-21. https://doi.org/10.1016/j.jfluidstructs.2012.08.007

[9] Rahman, Md Mahbubar, Md Mashud Karim, and Md Abdul Alim. "Numerical investigation of unsteady flow past a circular cylinder using 2-D finite volume method." *Journal of Naval Architecture and Marine Engineering* 4, no. 1 (2007): 27-42. https://doi.org/10.3329/jname.v4i1.914

[10] HAIDER, M. JIBRAN, S. Noman Danish, W. A. Khan, S. Uzair Mehdi, and Bilal Ahmed Abbasi. "Heat transfer and fluid flow over circular cyclinders in cross flow." *NUST Journal of Engineering Sciences* 3, no. 1 (2010): 67-77.

[11] Mushatet, Khudheyer, and Sarah Nashee. "Experimental and computational investigation for 3-D duct flow with modified arrangement ribs turbulators." *Thermal Science* 25, no. 3 Part A (2021): 1653-1663.

[12] Mushatet, K. S., and H. M. Hmood. "Numerical investigation for heat transfer enhancement in a triangular twisted tube." *ARPN Journal of Engineering and Applied Sciences* 16, no. 5 (2021): 593-599.

[13] Pasha, Amjad Ali, Meshal Nuwaym Al-Harbi, Surfarazhussain S. Halkarni, Nazrul Islam, D. Siva Krishna Reddy, S. Nadaraja Pillai, and Ufaith Qadiri. "CFD study of Convective Heat Transfer of Water Flow Through Micro-Pipe with Mixed Constant Wall Temperature and Heat Flux Wall Boundary Conditions." *CFD Letters* 13, no. 7 (2021): 13-26. https://doi.org/10.37934/cfdl.13.7.1326

[14] Krall, K. M., and E. R. G. Eckert. "Heat transfer to a transverse circular cylinder at low Reynolds numbers including rarefaction effects." In *International Heat Transfer Conference Digital Library*. Begel House Inc., 1970. https://doi.org/10.1615/IHTC4.2380