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Effect of Triangular Wake Splitter on Flow and Heat Transfer over a Circular Cylinder for Various Chord Lengths

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Abstract—The present work is an initiative towards improving heat transfer and reducing drag for the case of flow past cylinder by utilizing triangular wake splitter. Flow and heat transfer analysis has been carried out for three configurations-circular cylinder and cylinder with triangular and rectangular wake splitter from which it has been observed that cylinder with triangular splitter is the best configuration. Hence in the present study we have carried out flow and thermal analysis for triangular wake splitter of different chord lengths. Study has been carried out for low Reynolds number 5, 20, 40, 50, 60, 80, 100,200. Flow and thermal analyses have been performed for the case of constant wall temperature. Fluent 6.2.16 is used for the purpose of analysis. An incompressible SIMPLEC finite volume code employing a non-staggered grid arrangement is used. Second order upwind scheme is used for convective terms. Time discretization is implicit and a Second order Crank-Nicholson scheme is employed. Effect of wake splitter and wake splitter chord length on wake formation, vortex generation, coefficient of drag, local Nusselt number, coefficient of pressure heat transfer coefficient, overall heat transfer has been numerically studied and variations have been plotted. Validation has been carried out for average Nusselt number on single cylinder for Reynolds number 200 and coefficient of drag for Reynolds number 5 to 100 and results were found to be in good agreement with available experimental and numerical work. Heat transfer with triangular wake splitter has been found to be 17%, 53.4%, 115.7% more and drag coefficient 1.176, 7.92 and 9.01 times lower compared to bare cylinder for three different chord lengths. Performance of triangular wake splitter has been found to be similar to rectangular wake splitter. Results point towards cylinder with triangular wake splitter being more efficient than other configurations.

Keywords- CFD-FLUENT, Coefficient of drag, Nusselt number, Rectangular and Triangular wake splitter.

1 INTRODUCTION

PRESENT study considers numerical investigation for incompressible flow over cylinder of diameter D with and without wake splitter and effect of chord length onn various flow and thermal properties. Flow over cylinder is a fundamental heat transfer problem which is of practical importance having large number of applications. It involves analyses of fluid motion, wake formation and its effect on heat transfer. Applications which involve flow past cylinder include cross flow around rod bundles in heat exchangers of nuclear reactors, cooling of electronic equipments, air flow around cooling towers, flow past flame stabilizers in high speed combustion chamber, pipelines etc. However, as Reynolds number increases, flow begins to separate behind the cylinder causing symmetric wake. Wake is a region of recirculating flow behind a body caused due to flow separation. Attached and symmetric flow takes place for very low Reynolds number.

formation below Reynolds number 50 and Von Karman vortex shedding at higher Reynolds number. Wake formation reduces convective heat transfer downstream because of low velocity recirculation. To overcome this problem, splitter plates are used downstream. Splitter plates are wake stabilizers and have been used as a means of controlling various aspects of wake formation and vortex shedding. Wake splitter is a rigid attachments to the body which alters shedding frequency and increases base pressure resulting in overall reduction of drag. Even though it reduces average heat transfer coefficient, it provides additional surface for convective heat transfer and increases overall heat transfer. Various configurations of splitter plates can be used for enhancement of heat transfer and controlling vortex shedding. Hence wake splitters can be used to optimize heat transfer for flow past a bluff body as they reduce drag force acting on bluff body and increase overall heat transfer. Work has been carried out by Oosthuizen and Mansingh [1] on two dimensional square cylinder with splitter plates. Tiwari, Chakraborty, Biswas, Panigrahi [2] have worked on circular cylinder with splitter plate of different length and their effect on coefficient of pressure, local Nusselt number and overall heat transfer. Anderson and Szewczyk [3] have worked on circular cylinder for near subcritical Reynolds number. Mahir and Zekeriya [4] have worked on Convective heat transfer in usteady flow past two cylinder in tandem arrangement with variation of L/D ratio(center to center distance ratio) Local Nusselt number ,Strouhal number, flow parameters were studied for Re=100 and Re=200. Sudhakar and Vengadesan [5] have carried out work on oscillating rectangular wake splitters and its effect on flow characteristics. Panchal and Lakdawala [6] have worked on flow over square array of circular cylinders for L/D ratio(center to center distance) 1.25 for Re=40,50,100,150&200

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for different prandlt number. Study on wake generation and change in local Nusselt number was studied .Patnaik, Seetharamu, Aaswathanarayana [7] have worked on heat transfer for laminar flow past circular cylinder with integral wake splitter. Chandra and Chhabra [8] has carried out study on. Natural convection Heat transfer from a heated semi circular cylinderfor the various boundary condition ie constant temperature and constant heat flux for various Grshaoff number and prandtl number. Sparrow and Kang [9] have studied heat transfer and pressure drop characteristics on longitudinally finned tube banks. Roshko [10] studied vortex shedding suppression by using splitter plate in circular tube. Badami, Shrivastava, Hiremath, Saravanan, Seetharamu [11] have studied effect of rectangular and triangular splitter plates on cylinder and their effect on wake length, coefficient of pressure and coefficient of drag. Shrivastava, Badami, Hiremath, Saravanan, Seetharamu [12] have carried out numerical investigation of heat transfer in cylinder with triangular and rectangular splitter and their effect on average Nusselt number and overall heat transfer. Roshko [13] carried out study on wake width and vortex shedding characteristics. Fluent All these studies have been carried out with rectangular splitter plates and at Reynolds number higher than 100. In the present study, we have compared drag coefficient and heat transfer of cylinder with triangular wake splitter with bare cylinder and cylinder with rectangular wake splitter . Variation of above mentioned parameters have then been studied with change in chord length of triangular splitter. Reynolds number has been varied from 5 to 100. In the present work, two dimensional unsteady viscous incompressible flow over circular cylinder with and without integral wake splitter is studied. Air is considered as fluid at standard atmospheric pressure and temperature 300 K ($T\infty$). Analysis is done for Reynolds number (ReD) 5, 20, 40, 50, 60, 80, 100. For cylinder with rectangular wake splitter, length of wake splitter (LW) is taken equal to diameter (LW/D =1). For triangular wake splitter, three configurations have been studied, length of wake splitter is taken equal to diameter, one and half times diameter and twice diameter (LW/D =1, 1.5, 2). Wall (cylinder and splitter plate) temperature (TW) is maintained constant at 320 K. For a particular Reynolds number, average surface Nusselt number, average surface heat transfer coefficient, coefficient of drag and wake formation has been studied and compared for the three configurations.

Nomenclature

ReD = Reynolds number with diameter

$T\infty$ = Free stream temperature

TW = Temperature of cylinder (and splitter)

$U\infty$ = Free stream velocity

LW = Length of wake splitter

Pr = Prandtl number

Pe = Peclet number

Nu = Nusselt number

Havg= Heat transfer coefficient

AO= surface area of bare cylinder

AT = surface area of cylinder with triangular splitter

AR= surface area of cylinder with rectangular splitter

Q0 = Heat transfer by bare cylinder

QT= Heat transfer by cylinder with triangular splitter

QR= Heat transfer by cylinder with rectangular splitter

CD =Coefficient of drag

L= length of domain

μ = Coefficient of viscosity

CP = specific heat capacity at constant pressure

K = thermal conductivity

FD= Drag force

2 GRID AND MESH USED

Computational domain has been shown in Fig. 1 Domain length in flow direction was taken as L1= 42.5D and width in transverse direction as L2= 25D. Centre of tube was at a distance of L3=12.5D from inlet. In the case of cylinders with wake splitter, wake splitter length has taken to be equal to diameter.

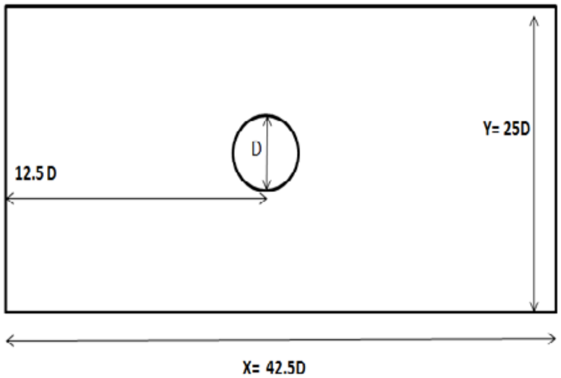

Fig 1 Grid

Mesh used for all the three cases have been shown in the Fig. 2(a), Fig .2(b), Fig. 2(c).

A 200x 130 grid has been used for the all the cases with 211058 elements.

Fine meshing has been done around cylinder, wake splitter as well as downstream to capture vortex shedding as well as for better accuracy. Grid refinement study was also done to verify grid independence and accuracy of method.

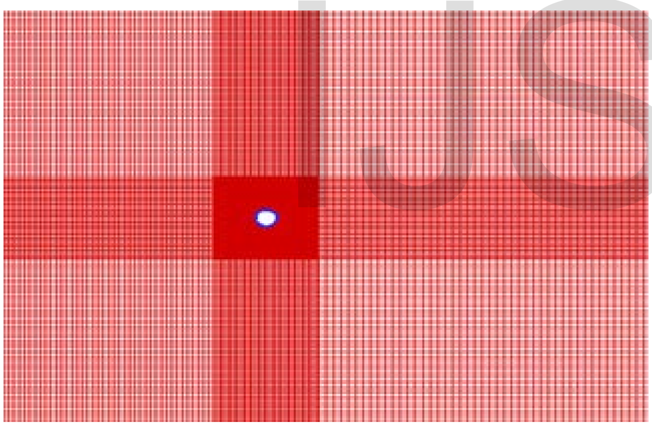

Fig 2(a) Mesh for bare cylinder

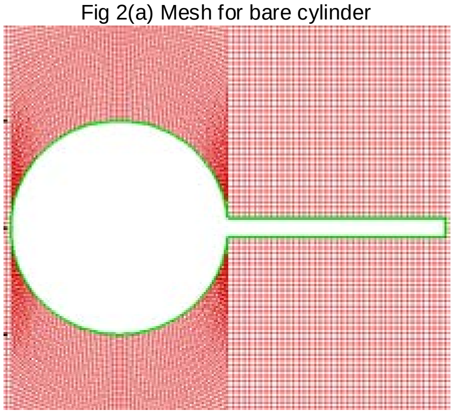

Fig 2 (b) Mesh for cylinder with rectangular splitter

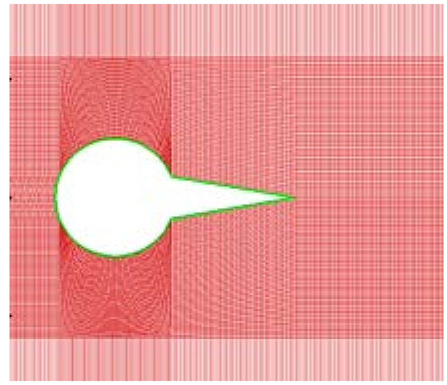

Fig 2 (c) Mesh for cylinder with triangular splitter

3 GOVERNING DIFFERNTIAL EQUATIONS AND DIMENSIONLESS PARAMETERS

Continuity Equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

X-Momentum Equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{Re}\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] \tag{2}$$

Y-Momentum Equation

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} + \frac{1}{Re}\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] \tag{3}$$

Energy Equation

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{Pe}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] \tag{4}$$

Re= Reynolds number = ρ u∞ D / μ

Pr = Prandtl number = μ CP / k

Pe = Peclet number = Re * Pr

Nu = Nusselt number = H D/ k

CD = coefficient if drag = FD/ 0.5 ρ u∞2D

4 BOUNDARY CONDITION

Governing differential equations are solved for following differential equations

1) At outer left inlet boundary (channel inlet), uniform velocity in x-direction.
$u=U_\infty$, $v=0$, $T=T_\infty=300$ K

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2) At cylinder surface, no slip condition and constant temperature.
   u=0, v=0, T_W = 320 K
3) At outflow boundary, constant pressure condition.
   $P = P_\infty$
4) At top and bottom wall, no slip condition.
   u=0, v=0

5 METHODOLOGY

Mesh has been created using Gambit 2.2.30 and have been shown in Fig. 2. Fine meshing has been done to ensure accurate results. Fluent 6.2.16 has been used for analysis. An incompressible SIMPLEC finite volume code employing non staggered grid arrangement has been used. Second order upwind scheme is used for convective terms. Time discretization is implicit and a second order Crank-Nicholson scheme is employed. Time step size of 0.01s is given. Residual convergence criterion was satisfied using an upper bound of 10-6.

6 RESULTS AND DISCUSSION

6.1 Validation For Single Cylinder

Validation for both coefficient of drag and Local and average Nusselt number has been carried out with standard results and present results have been found to be in good accordance with standard results.

The present analysis for flow over heated cylinder has been validated for average Nusselt number at ReD =200 with available numerical results of [4]. [5]. and with values obtained from correlations from Zhuauskas, Knudsen et al. and Churchill et al. the comparison in given in TABLE I

TABLE I

COMPARISON OF AVERAGE NUSSELT NUMBER FOR VALIDATION

ReD	Pres-ent stud y	Mahir N et al.	Zhua-skas	Knud-sen Et al.	Churc-hill et al.
200	7.1 6	7.474	7.21	7.16	7.19

Variation of local Nusselt number (along circumference of bare cylinder) has also been compared with results from [4] and [5]. The comparison has been presented in Fig. 3. The present simulation of flow past circular cylinder was validated for drag coefficient, with varying Reynolds number 5, 20, 40.50,80,100 with the available numerical results. Results have been shown in TABLE III

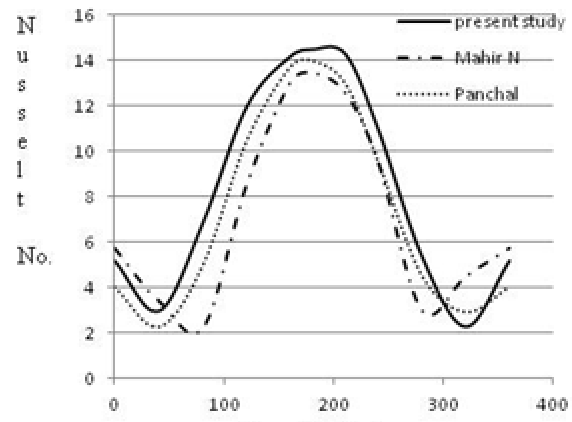

Fig 3 Comparison of local Nusselt number along circumference (Nu vs Theta)

Present curve behaviour is found to match with that of [4],[5]. There is minor variation in maximum Nusselt number value and separation point which can be attributed to meshing differences around surface, different code used, different grid convergence criterion and iterations. Average nusselt number has been found to be in good agreement with available literature and standard correlations. The corrélations used have been mentioned in TABLE II.

TABLE II

CORRÉLATIONS

Author	Correlation
Zhuaskas	Nu=0.51Re1/2
Knudsen et al.	Nu=0.683Re0.466Pr0.333
Churchill Et al.	Nu=0.3+0.62Re0.5Pr0.33 x [1+(0.4/Pr)2/3]1/4 [1+ (Re/282000)5/8]4/5

TABLE III

COMPARISON OF MEAN DRAG COEFFICIENT WITH THOSE OF OTHER AUTHORS

Re	Present work	Dennis and chang	Sucker and Brauer	Silva and neto

		[2]	[3]	[5]
5	5.92	-	-	-
20	2.254	2.05	2.08	2.04
40	1.706	1.52	1.73	1.54
50	1.55		1.65	1.46
80	1.46		1.51	1.40
100	1.45		1.45	1.39

7 FLOW CHARECTERSTICS AND CONTOURS

The Fig.7 (a),(b),(c), Fig.8(a),(b),(c), Fig.9(a),(b),(c) show comparison of velocity streamlines for bare cylinder and cylinder with triangular wake splitter of chord length 1D, 1.5D, 2D. TECPLOT has been used to obtain streamlines. For Reynolds number 5 for all chord lengths, flow remains attached to surface. Flow behaves as a potential flow dominated by viscous force and doesn't separate. As Reynolds number increases, inertial forces become strong enough to overcome viscous force and flow separates. This can be seen from recirculating wakes formed for higher Reynolds number. With increase in Reynolds number, length of wake increases till attainment of critical Reynolds number which is in good agreement with linear stability theory. Beyond this, Von-Karman vortex shedding was observed.

Effect of increase in length of splitter plate can be seen clearly for higher Reynolds number. For chord length 1D, minor asymmetry can be observed for Reynolds number 40 while wake s are symmetric for the case of 1.5D and 2D. The effective wake lengths on either side is also less which gives rise to higher back pressure and lesser drag. For Reynolds number 100, asymmetrical vortex shedding can be observed for chord length 1D and 1.5D. However, wakes are almost symmetrical for chord length 2D. The main purpose of using wake splitter is to delay flow separation and the onset of Von Karman vortex shedding and reduce flow induced vibration. This can be clearly seen in the above cases.

It can be clearly seen that splitter plate influences the pressure drop characteristics. Wake splitter prevents interaction of separated layers on either side. Streamline plots also show a significant reduction in wake length with splitter plates as compared with bare cylinder. Coefficient of drag for all cases has been tabulated later and it is observed that triangular wake splitter offers least drag due to better streamlining of flow. Base pressure has been found to be higher for the case with triangular wake splitter with chord length 2D as compared to splitter with chord length 1D AND 1.5D and bare cylinder leading to reduction in drag. It is observed that length of wake increases with Reynolds number till critical Reynolds number of separation.

8 TEMPERATURE DISTRIBUTION

Fig.4 (a),(b),(c), Fig.5(a),(b),(c) Fig.6 (a),(b),(c), Fig.7(a),(b),(c) show temperature and Nusselt number distribution for all configurations for various Reynolds number. Front surface has highest clustering of temperature isotherms which indicates high temperature gradients and hence high local Nusselt number. Incoming fluid strikes stagnation line and removes heat. After this it gradually gains thermal energy and Its temperature increases Local Nusselt number decreases along the surface of cylinder from front stagnation point to rear stagnation (separation point) point which can be attributed to thickening of thermal boundary layer. For the case with wake splitter, local Nusselt number is maximum at front stagnation point, reduces along surface of cylinder, very low on the surface of wake splitter with a sharp increase at θ = 1800. At splitter plate part, it is observed that as fluid progresses towards tip of the plate, its temperature reduces even though temperature remained pretty high. This can again be attributed to streamlining of flow by splitter plate and high clustering of temperature isotherm. Nusselt number has been found to be low in recirculation region. This can be attributed to low velocity recirculation causing poor heat transfer. Also it is found to increase again from rear stagnation point to front. Splitter plate reduces local heat transfer rate because of ceasing of interaction of vortices on either side. However it compensates for it by an increase in heat transfer surface and hence increasing overall heat transfer. Nusselt number for triangular has been found to be higher than rectangular splitter and can be attributed to better streamlining of flow. Nusselt number for triangular splitter reduced with increase in chord length which can be attributed to larger splitter area being exposed to hot

STREAMLINES AND TEMPERATURE CONTOURS FOR DIFFERENT CHORD LENGTHS

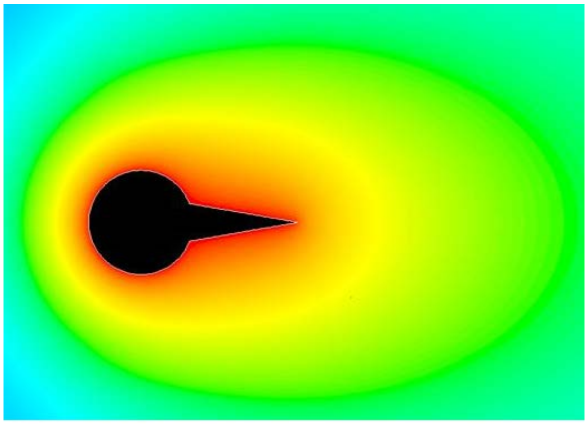

Fig.4(a) Cylinder with triangular splitter with chord length 1D (Re=5)

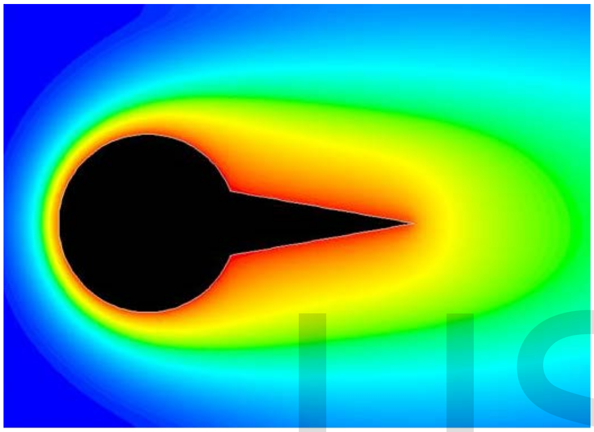

Fig.4(b) Cylinder with triangular splitter with chord length 1D (Re=40)

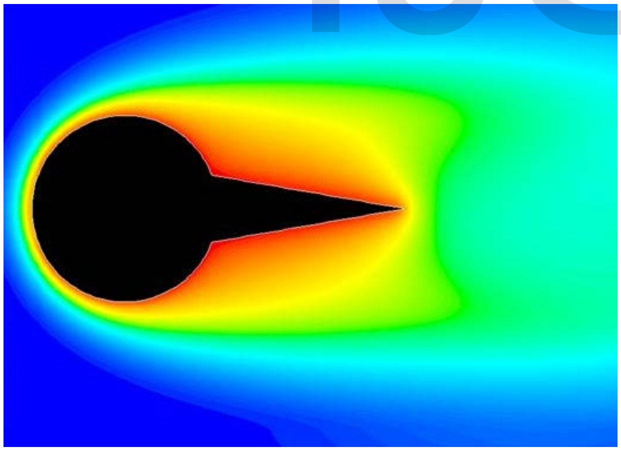

Fig.4 (c) Cylinder with triangular splitter with chord length 1D (Re=100)

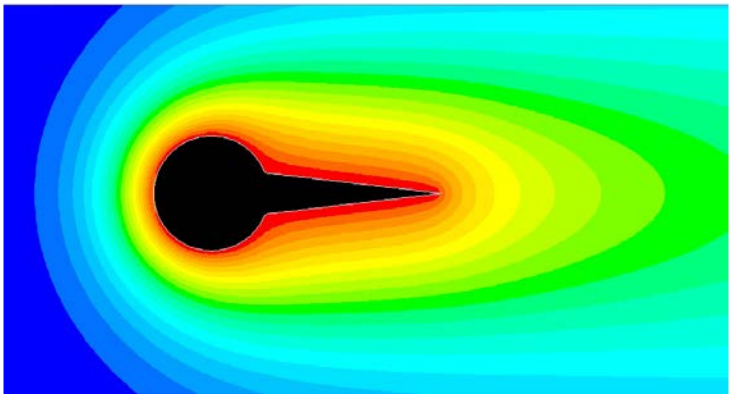

Fig.5(a) Cylinder with triangular splitter with chord length 1.5D (Re=5)

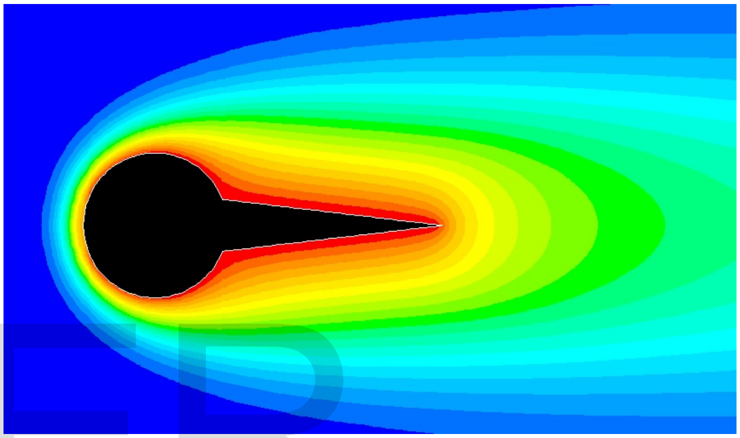

Fig.5(b) Cylinder with triangular splitter with chord length 1.5D (Re=40)

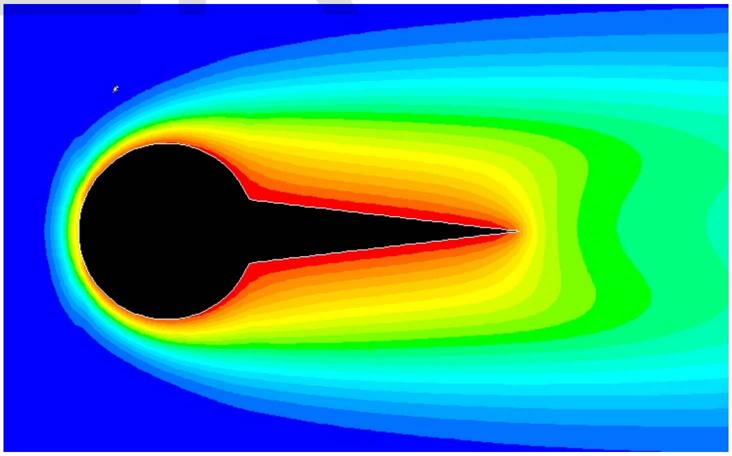

Fig.5(c) Cylinder with triangular splitter with chord length 1.5D (Re=100)

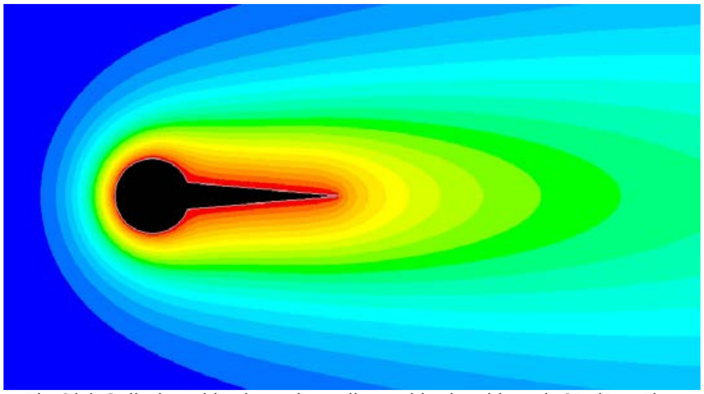

Fig.6(a) Cylinder with triangular splitter with chord length 2D (Re=5)

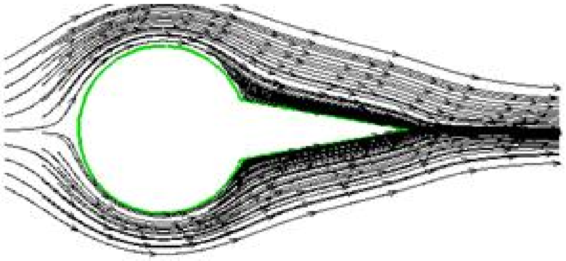

Fig. 7(a) Cylinder with triangular splitter with chord length 1D (Re=5)

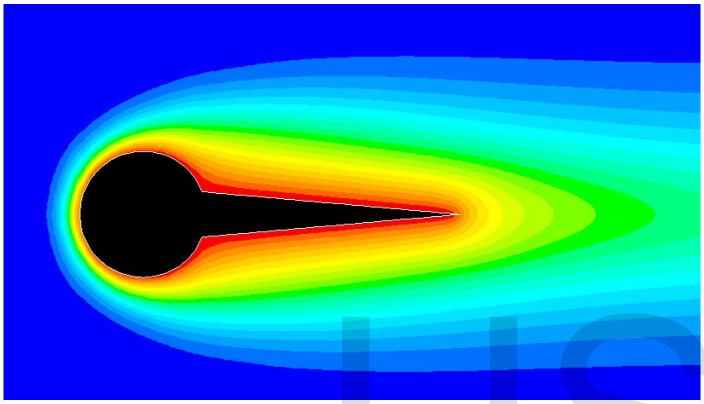

Fig.6(b) Cylinder with triangular splitter with chord length 2D (Re=40)

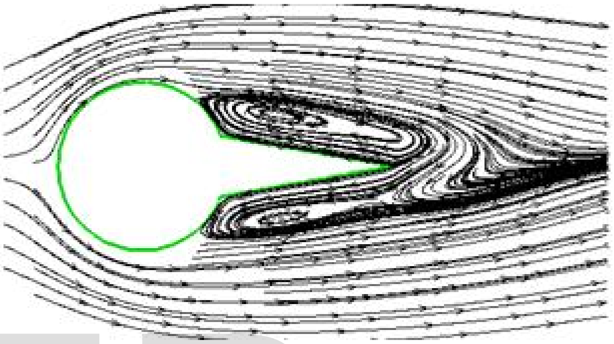

Fig. 7(b) Cylinder with triangular splitter with chord length 1D (Re=40)

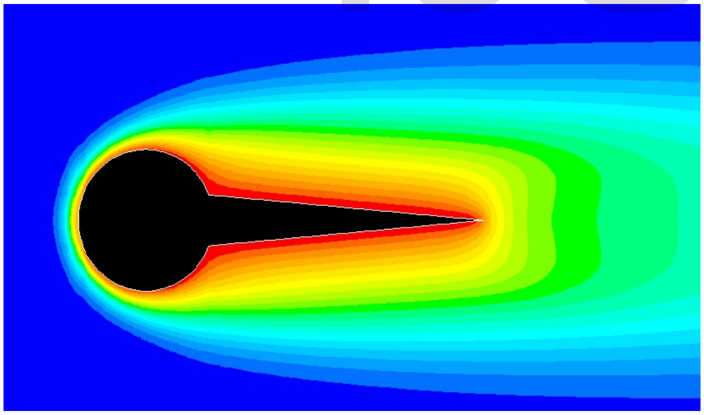

Fig.6(c) Cylinder with triangular splitter with chord length 2D (Re=100)

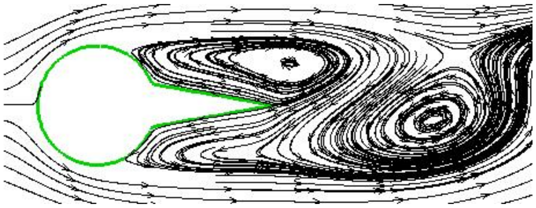

Fig 7(c) Cylinder with triangular splitter with chord length 1D (Re= 100)

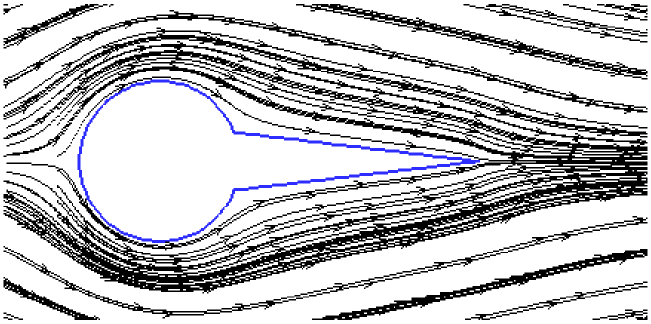

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Fig. 8(a) Cylinder with triangular splitter with chord length 1.5D (Re=5)

Fig. 8(b) Cylinder with triangular splitter with chord length 1.5D (Re=40)

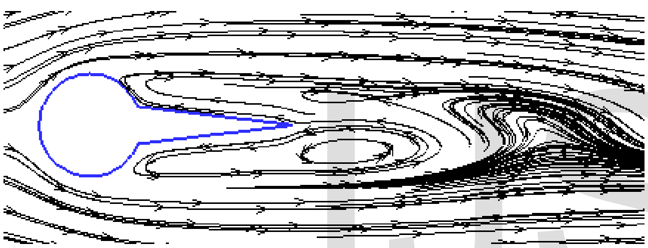

Fig 8(c) Cylinder with triangular splitter with chord length 1.5D (Re= 100)

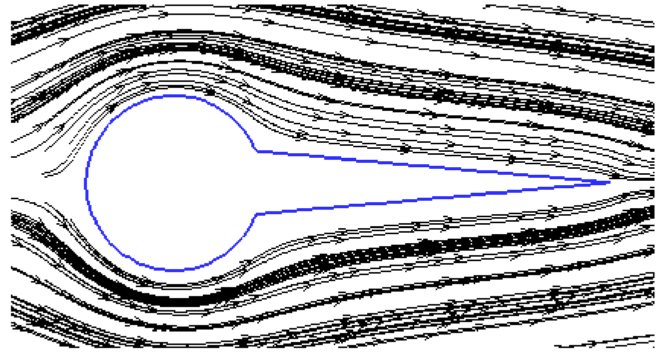

Fig. 9(a) Cylinder with triangular splitter with chord length 2D (Re=5)

Fig. 9(b) Cylinder with triangular splitter with chord length 2D (Re=40)

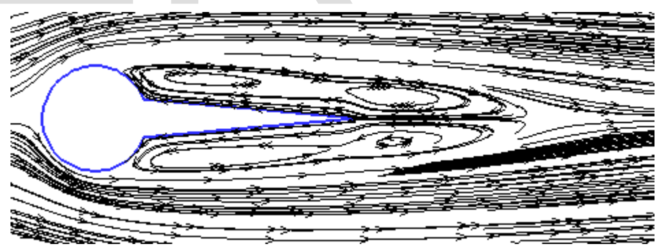

Fig 9(c) Cylinder with triangular splitter with chord length 2D (Re= 100)

recirculating fluid in wake zone. Fig. 4-9 show temperature contours, and stream traces for Re= 5, 40, 100. Re = 5 is the case of attached flow, Re = 40 is the case of symmetric wake, Re = 100 is the case of Von Karman unsymmetrical vortex shedding. The three cases were chosen to compare parameters at different flow pattern. Heat transfer coefficient followed

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same pattern of distribution and hence has been shown only for Re=100.

9 QUANTITATIVE RESULTS

9.1 Comparison For All The Three Configurations

9.1.1 Effect Of Reynolds Number On Coefficient Of Drag

Coefficient of drag has been found to decrease with increase in Reynolds number. Also coefficient of drag for triangular wake splitter (CD,T) has been found to be lower than rectangular wake splitter (CD,R) and bare cylinder (CD,O). This is because streamlining of flow is better with triangular wake splitter as compared to rectangular wake splitter and bare cylinder leading to reduced drag force. Values of coefficient of drag for various Reynolds number have been shown in TABLE IV. Drag coefficient of rectangular splitter to triangular splitter (CD,R / CD,T) shows that drag offered by triangular splitter is slightly lesser than rectangular splitter.

TABLE IV

VARIATION OF COEFFICIENT OF DRAG WITH REYNOLDS NUMBER

Re_D	$C_{D,O}$	$C_{D,R}$	$C_{D,T}$	$C_{D,R}$ / $C_{D,T}$	$C_{D,O}$ / $C_{D,T}$
5	5.92	5.28	2.04	2.58	2.9
20	2.354	2.358	2.351	1.003	1.001
40	1.706	1.83	1.687	1.09	1.011
50	1.55	1.575	1.535	1.03	1.009
80	1.46	1.284	1.278	1.004	1.142
100	1.45	1.245	1.237	1.16	1.17

9.1.2 Effect of Reynolds number on heat transfer coefficient and average Nusselt number

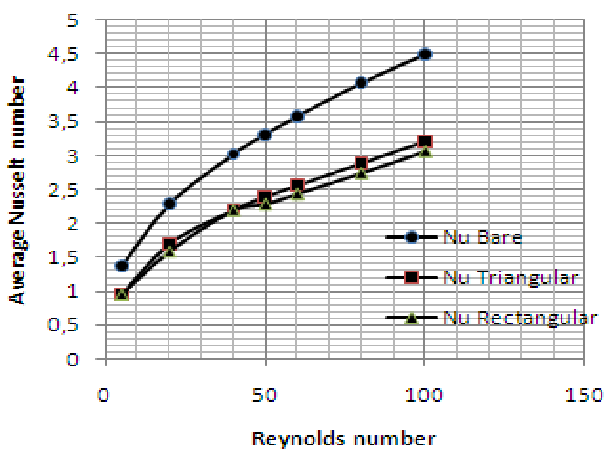

Fig.10 Variation of average Nusselt number with Reynolds number

Effect of Reynolds number on average surface heat transfer coefficient and average Nusselt number Surface heat transfer coefficient and Nusselt number have been found to increase with increasing Reynolds number and followed same trend for all three configurations. Surface heat transfer coefficient and average Nusselt number were found to be higher for bare cylinder (Havg,BARE) compared to cylinders with wake splitter. Among cylinders with wake splitter, heat transfer coefficient and Nusselt number for triangular wake splitter. (Havg,TRI) is found to be higher than rectangular wake splitter (Havg,RECT). Average heat transfer coefficient has been shown in TABLE V for all Reynolds number. Variation of average Nusselt number with Reynolds number has been shown in Fig. 10.

TABLE V

VARIATION OF AVERAGE SURFACE HEAT TRANSFER COEFFICIENT WITH REYNOLDS NUMBER

Re_D	$H_{avg,BARE}$	$H_{avg,RECT}$	$H_{avg,TRI}$
5	38.54	27.02	27.28
20	63.89	44.53	49.99
40	82.77	60.56	62.63
50	90.90	64.41	67.41
60	98.23	66.74	70.17
80	111.17	75.19	79.23
100	123.36	83.94	87.91

9.1.3 Effect on wake length

Wake length (Lw) in the present work is defined as distance between two stagnation point in the downstream of the cylinder. Splitter plates are used as passive means of controlling vortex formation and vortex shedding in the wake. It has been observed that with increase in Reynolds number, the length of wake increases for steady symmetric flow for the entire above mentioned configuration.

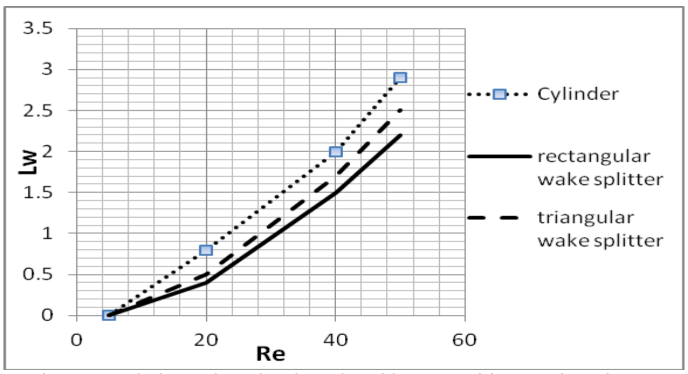

Fig 11 variation of wake length with Reynolds number for steady symmetric flow.

Fig 11 describes variation of wake length with increasing in Reynolds number for steady symmetric flow for bare cylinder,

cylinder with rectangular and triangular wake splitters. It is found that wake length for bare cylinder for all the cases of Reynolds number to be more when compared with triangular wake splitter & rectangular wake splitter. It is observed that the wake length for rectangular wake splitter was reduced by 33% and that of triangular wake splitter by 22% when compared to bare cylinder.

9.1.4 Effect of Reynolds number on overall heat transfer

Overall heat transfer has been found to be higher for the case of cylinder with triangular wake splitter as compared to bare cylinder and cylinder with rectangular wake splitter. Cylinder with rectangular splitter has surface area 1.66 times bare cylinder (AR/AO) and cylinder with triangular splitter has surface area 1.6 times bare cylinder (AT/AO). Even though bare cylinder has higher heat transfer coefficient, due to additional surface provided by wake splitters overall heat transfer has been found to be higher for the case of cylinder wake splitter. Another point to be noted is the fact that even with higher surface area, heat transfer with rectangular splitter is less compared to triangular.

TABLE VI

VARIATION OF OVERALL HEAT TRANSFER FOR CYLINDER WITH TRIANGULAR AND RECTANGULAR WAKE SPLITTER WITH REYNOLDS NUMBER

Re_D	A_R/A_O	(Q_R/Q_O)	A_T/A_O	(Q_T/Q_O)
5	1.66	1.17	1.6	1.1325
20	1.66	1.1632	1.6	1.2522
40	1.66	1.2211	1.6	1.2107
50	1.66	1.1826	1.6	1.1865
60	1.66	1.1339	1.6	1.1430
80	1.66	1.1285	1.6	1.1399
100	1.66	1.1356	1.6	1.1402

Heat transfer for rectangular wake splitter configuration has been found to be 16.2% greater than bare cylinder (QR/QO=1.1621) whereas triangular configuration has been found to be 17.3% higher than bare cylinder. This shows that triangular configuration is slightly better heat dissipater as compared to rectangular wake splitter. Results have been shown in TABLE VI.

9.2 Effect of variation of chord length of triangular splitter

9.2.1 Variation of local coefficient of pressure from stagnation point

Fig 12 shows variation of local coefficient of pressure with θ from stagnation point. Variations have been shown for Re= 50. Coefficient of pressure is maximum at $\theta = 0$ where cold fluid hits heated cylinder. As fluid moves forward along cylinder, it experiences a pressure drop which can be seen from drop in value of coefficient of pressure. Local pressure becomes less than atmospheric pressure around $\theta = 50$ after which coefficient of pressure becomes negative.

Back pressure has been found to be least for bare cylinder and increases with increase in chord length of triangular splitter. this can be seen from the plot where the drop in pressure is maximum for bare cylinder. This can be attributed to better streamlining of flow by splitter plate and a streamline extension through plate which leads to late separation. Size of wake is also reduced which leads to higher back pressure compared to bare cylinder which has a large wake zone behind it. Higher back pressure leads to lower drag for the case of cylinder with splitter plate.

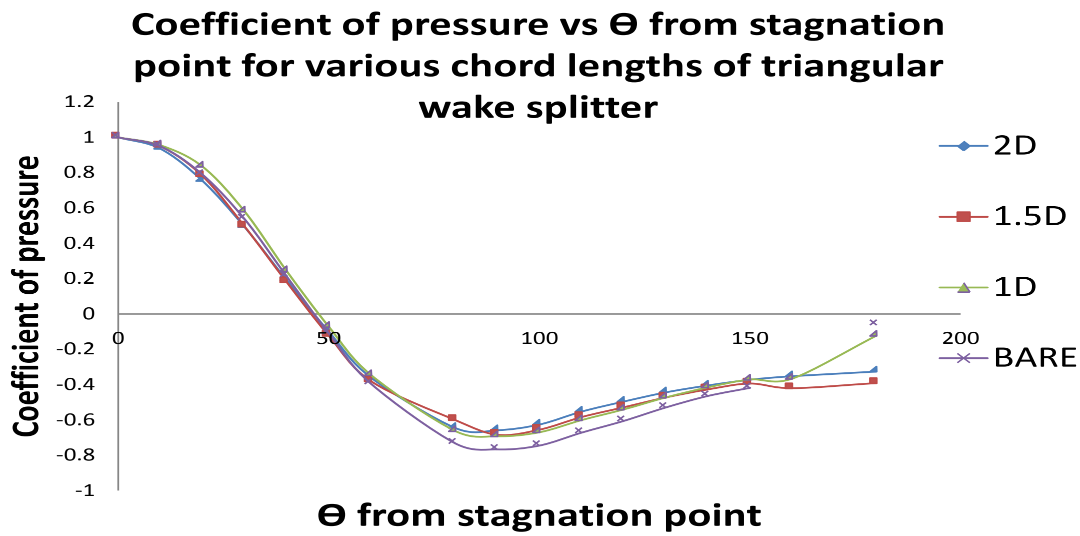

Fig.12 Variation of coefficient of pressure with Ө from stagnation point

9.2.2 Variation of local coefficient of pressure from stagnation point

Local Nusselt number is highest at the point of impact of fluid on cylinder. This is because of large temperature difference. As fluid moves forward, its temperature increases and hence convective heat transfer reduces. This leads to a drop in local Nusselt number as Ө increases. Value of local Nusselt number is least along wake splitter because of large surface area being exposed to hot recirculating fluid and low convective heat transfer. Fluctuations in local Nusselt number values can be attributed to recirculating flow which separates and then reattaches to cylinder wall.

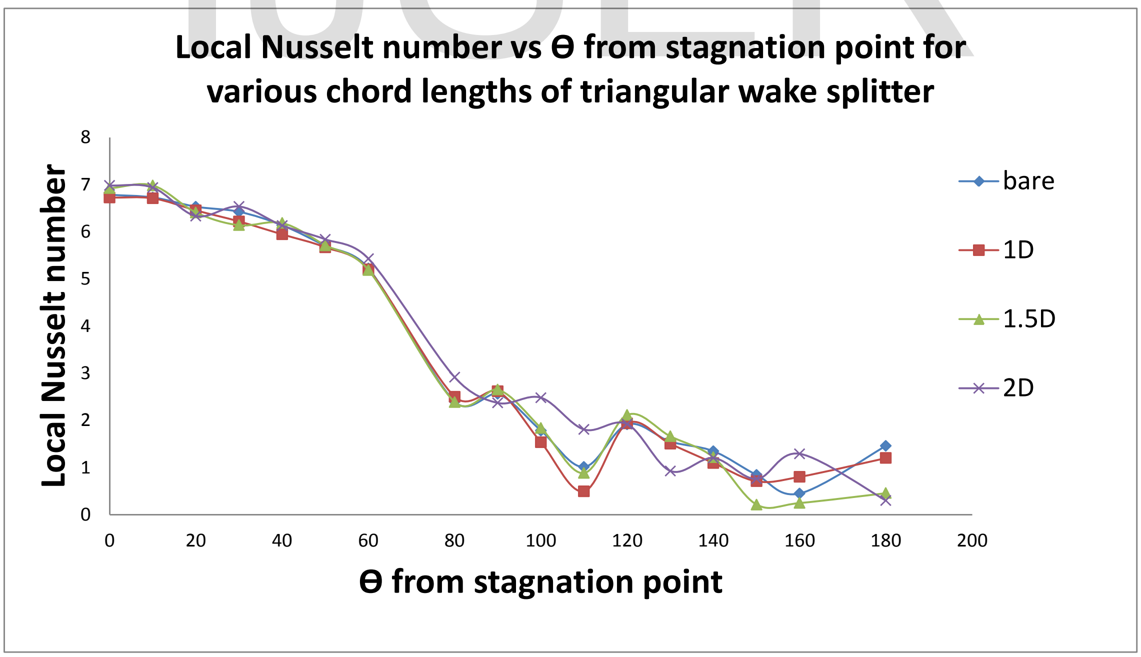

Fig.13 Variation of local Nusselt number with Ө from stagnation point

TABLE VII

VARIATION OF COEFFICIENT OF DRAG WITH CHORD LENGTH AND REYNOLDS NUMBER

Re	CD(Bare)	CD(1D)	CD(1.5D)	CD(2D)	CD,O / CD,T (1D)	CD,O / CD,T (1.5 D)	CD,O / CD,T (2D)
5	5.92	2.04	0.721	0.121	2.9	8.2108	48.9256
20	2.354	2.351	0.261	0.243	1.001	9.0192	9.6872
40	1.706	1.687	0.258	0.173	1.011	6.6124	9.8613
50	1.55	1.535	0.157	0.156	1.009	9.8726	9.9359
80	1.46	1.278	0.139	0.129	1.142	10.5036	11.3178
100	1.45	1.237	0.129	0.119	1.17	11.2403	12.1849

9.2.3 Effect Of Reynolds Number On Coefficient Of Drag

Coefficient of drag has been found to decrease with increase in Reynolds number for all the chord lengths. It has been observed that with increase in chord length of triangular splitter, coefficient of drag reduces significantly. coefficient of drag for triangular wake splitter with chord length equal to 2D (CD,T (2D)) has been found to offer least drag compared to triangular wake splitter with chord length equal to 1.5D (CD,T (1.5D)), 1D (CD,T (1D)) and bare cylinder (CD,O). This is because streamlining of flow is better with triangular wake splitter as compared to rectangular wake splitter and bare cylinder leading to reduced drag force. The longer the splitter plate, the later the separation takes place as wake splitter provides a streamlined extension of body which helps in delaying flow separation. Values of coefficient of drag for various Reynolds number have been shown in TABLE VII. Drag coefficient of bare cylinder to triangular splitter for different chord lengths (CD,O / CD,T) shows that drag offered by triangular splitter of higher chord lengths is lesser than rectangular splitter.

9.2.4 Effect of Reynolds number on heat transfer coefficient and average Nusselt number

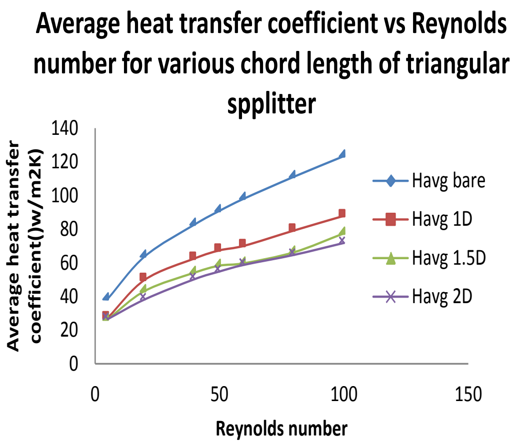

Fig.14 Variation of average heat transfer coefficient with Reynolds number

Effect of Reynolds number on average surface heat transfer coefficient has been studied for different chord lengths of triangular wake splitter and bare cylinder. Surface heat transfer coefficient and Nusselt number have been found to increase with increasing Reynolds number and followed same trend for all three configurations. Surface heat transfer coefficient was found to be higher for bare cylinder (Havg,BARE) compared to cylinders with triangular splitter for all chord lengths. Among cylinders with wake splitter, heat transfer coefficient for triangular wake splitter with chord length 2D (Havg,TRI)2D)) has been found to be higher than triangular wake splitter of chord length 1.5D (Havg,TRI(1.5D)) and 1D (Havg,TRI(1D)). Average heat transfer coefficient has been found to decrease with increase in chord length. This can be attributed to fact that an increase in chord length leads to larger area of splitter plate exposed to warm recirculating fluid leading to lower average heat transfer coefficient. Average heat transfer coefficient values for triangular splitter plates of different chord lengths have been shown in TABLE VII for all Reynolds number. Variation of average heat transfer coefficient with Reynolds number has been shown in Fig. 14.

TABLE VIII
VARIATION OF AVERAGE SURFACE HEAT TRANSFER COEFFICIENT WITH REYNOLDS NUMBER FOR VARIOUS CHORD LENGTHS OF TRIANGULAR SPLITTER

Re	Havg bare	Havg 1D	Havg 1.5D	Havg 2D
5	38.54	27.28	26.39	26.55
20	63.89	49.99	43.37	38.34
40	82.77	62.63	54.21	50.34
50	90.9	67.41	58.34	54.88
60	98.23	70.17	59.78	58.87
80	111.17	79.23	66.31	64.74
100	123.36	87.91	77.51	71.81

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9.2.5 Effect of Reynolds number on overall heat transfer

Overall heat transfer has been found to be higher for the case of cylinder with triangular wake splitter with chord length 2D as compared to bare cylinder and cylinder with triangular wake splitter of chord length 1.5D and 1D. Cylinder with triangular splitter has surface area 1.6, 2.4 and 3.5 times bare cylinder (AT/AO) for chord lengths 1D, 1.5D and 2D respectively. Even though bare cylinder has higher average heat transfer coefficient, due to additional surface provided by wake splitters overall heat transfer has been found to be higher for the case of cylinder triangular wake splitter. Overall heat transfer for triangular wake splitter configuration has been found to be 17.3% , 53.4%, 115.7% greater than bare cylinder (QT/QO) for chord lengths 1D, 1.5D and 2D respectively. Results have been shown in TABLE XI.

TABLE IX

VARIATION OF OVERALL HEAT TRANSFER FOR CYLINDER WITH TRIANGULAR WAKE SPLITTER OF DIFFERENT CHORD LENGTHS WITH REYNOLDS NUMBER

Re	AT/Ao (1D)	QT/QO(1D)	AT/Ao (1.5D)	QT/QO (1.5D)	AT/Ao (2D)	QT/QO (2D)
5	1.6	1.1325	2.4	1.6434	3.55	2.4456
20	1.6	1.2522	2.4	1.6292	3.55	2.1303
40	1.6	1.2107	2.4	1.5529	3.55	2.1591
50	1.6	1.1865	2.4	1.5403	3.55	2.1433
60	1.6	1.143	2.4	1.4606	3.55	2.1275
80	1.6	1.1402	2.4	1.4315	3.55	2.0673
100	1.6	1.1721	2.4	1.508	3.55	2.0665

10 CONCLUSION

Numerical analysis has been performed for flow past cylinder with and without wake splitter using fluent version 6.2.16. Results of coefficient of drag and heat transfer have been consolidated and it can be concluded that overall heat transfer for cylinder with triangular splitter 17% greater than bare cylinder and similar to rectangular wake splitter having 4% larger surface area. Coefficient of drag for triangular splitter configuration has been found to be lower than bare cylinder by 8% and similar to cylinder with rectangular wake splitter. This makes cylinder with triangular splitter best possible configuration for optimum heat transfer. Heat transfer with triangular wake splitter has been found to be 17%, , 53.4%, 115.7% more and drag coefficient 1.176, 7.92 and 9.01 times lower compared to bare cylinder for three different chord lengths.

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