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Effect of Triangular Splitter on Heat Transfer and Fluid Flow over Triangular Cylinder

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Abstract

A numerical study of fluid flow and heat transfer around triangular cylinder with using triangular splitter at different splitter length (L), splitter base (S) and Reynolds number is investigated. A modern CFD code ANSYS FLUENT v 16.1 is used to simulate fluid flow and heat transfer around triangular cylinder with and without using triangular splitter. the splitter length and base is changed (L/b=0.25, 0.5, 1, 1.5) and (S/b=0.35, 0.45) respectively with different Reynolds number ($20 \leq Re \leq 200$). Enhancement in heat transfer with reduced drag is found around triangular cylinder with using triangular splitter. Nusselt Number around triangular cylinder with using triangular splitter is enhanced by (9.5 % - 24.5 %) and drag reduced by (21 % -34.6 %) as compared to the bare triangular cylinder

Keywords: CFD; FLUENT; Heat Transfer; drag; triangular cylinder; splitter

INTRODUCTION

Heat transfer and fluid flow around cylinder with different shapes are very complex due to the vortex shedding behind the cylinder. When flow around the cylinder increasing, the separation of flow from cylinder will be occur causing symmetric wake. Wake is the region of recirculating flow behind a cylinder happening due to separation. This phenomenon is responsible for actuating forces on the body that may cause structural vibrations, acoustic noise emissions and sometimes resonance triggering the failure of structures. Thus, it is important from engineering point of view to investigate flow around different shapes of cylinders. When Reynolds number increases a wake will be increasing and generate large unsteady forces Dey and Das [1]. The fluctuating periodic forces generated on the cylinder with different shapes due to the vortex shedding led to damage the structure thereby shorting life of the structure Soumya and Prakash [2]. Flow around the cylinder has a number of applications in heat exchangers of flow around cooling towers, cooling of electronic, nuclear reactor et. al. at increasing Re, Von Karman vortex shedding will be appearing and the wake behind the cylinder led to reduce convective heat transfer Shrivastava et al [3]. To overcome this problem, many methods may be using to resolving this problem as using winglets, splitters, arrangement the cylinders with different types or using cylinders with different shapes.

One method using to overcome this problem are using splitter plates placed behind the cylinder and the wake of flow will be controlling the flow and vortex shredding. Splitters increases the pressure of base resulting in overall reduction of drag Shrivastava et al [3].

Various configurations of splitter plates are using to enhanced heat transfer with controlling vortex shedding behind the cylinders and reducing drag forces acting on a cylinder. number of studies has been done for enhancement heat transfer and reduced drage around different shapes of cylinder with using different methods. where Singha et al [4] performed heat transfer from circular cylinder in the vicinity of plane wall numerically with ($20 \leq Re \leq 200$) and gap- ratio between cylinder and wall (0.1-2.5), the study shows that a critical gap – ratio is to be maintained to achieve effective heat transfer from cylinder. Jeon et al [5] conducted heat transfer around circular cylinder with heat source numerically. The study examined effect of Reynolds number on temp. around cylinder and shows that the maximum temperature inside the cylinder decreased as Re increasing and maximum temperature move from the center to the rear of cylinder till (Re=20) Dhiman et al [6] studied the flow and heat transfer characteristic around isolated square cylinder with ($1 \leq Re \leq 45$) and ($0.7 \leq Pr \leq 4000$), ($Pe \leq 4000$) with blockage ratio (β=1/8, 1/6,1/4). Dey and kumar [7] investigated the effect of corner radius and nanofluid volume fraction on heat transfer from square cylinder at (Re=100). The corner radius was varying from (r=(0.5D-0.71D)). the result shows that the heat transfer amount was maximum at (r=0.5). Zeitoun et al [8] investigated 2-D heat transfer and fluid flow around a triangular cylinder with ($Re \leq 200$) numerically. The result shows that critical Reynolds number (Re_{cr} =38.03) for vortex of triangular cylinder facing the flow and (Re_{cr}=34.7) for base of triangular cylinder facing the flow. Farhadi et al [9] a numerical study has been carried out to analysis fluid flow and heat transfer around two isothermal triangular cylinders placed staggered in horizontal channel with (Re=100, 250, 350) at lateral ratio (0, 0.5, 1) and longitudinal gap ratio (1, 2, 3, 4). The vortex shedding was disappearing when obstacles placed in close vicinity of channel. De and Dalal, [10] study heat transfers and flow around triangular cylinder placed in channel with ($80 \leq Re \leq 200$) and blockage ratio($1/12 \leq \beta \leq 1/4$). The result shows that Strould number and lift coefficient dependent on β and Re.

Also Dey and Das, [1] conducted the effect of thorn (a triangular extended solid) attached to square cylinder on the drag, pressure, shear stress, boundary layer and viscous force at (Re=4) with different length (L/D=0.2, 0.4, 0.6) and different inclination. The result explains that the heat transfer will be decreasing around square cylinder by (2-3%) with using thorn. [2] investigated the fluid flow characteristic around triangular cylinder with using splitter plate with different length (0≤L/b≤6) at (500≤Re≤200) where L is the splitter plate length and (b) side cylinder. The drag around the cylinder will be decreasing with attachment the splitter plate, also the specific value of Re and the drag is minimizing at particular splitter plate length and the drag is minimized from (9% -57%) by attaching splitter plate with different Re when comparing with bare triangular cylinder. Shrivastava et al [3] performed the improving heat transfer and reduce drag for flow past circular cylinder with triangular and rectangular wake splitter at (5≤Re≤200). The result explains that heat transfer improved with using wake splitter. And triangular splitter is the best for enhanced heat transfer by (17% - 115.7%) with less drag coefficient compared to the bare cylinder. Paavan et al [11] investigated the effect of two types of splitters (triangular and rectangular) on pressure coefficient and drag around circular cylinder at (Re=5, 20, 40, 50, 80, 100), the wake with rectangular splitter less than the triangular and coefficient of drag was less for triangular than the rectangular and the drag for cylinder with splitter was less when compared with bare cylinder. Dey and Das, [12] studied the flow around square cylinder with rounded edges numerically at (5≤Re≤45) and blockage ratio 0.05, from the results the drag coefficient and pressure coefficient is decreasing with increasing corner radius also B.L thickness decreasing. Yagmur et al [13] studied the separation of flow by using different shapes of cylinder exposed to cross flow at (Re=5000, 10000). It shows that the wake length in x and y directions and size of the foci of streamline are decreases by increasing Re. Manish K. et al.[15] study the flow around square cylinder with splitter plate at intermediate Reynolds number the results shows that the plate modifies the wake size and flow structure behind the cylinder. The drag coefficient and the Strouhal number decrease with an increase in splitter plate length.

A different method as the end plate, splitter, for controlling the flow of secondary cylinder in the wake and vertical plate up stream of body are used to control the vortex shedding [1]. Efforts of studies around different shapes of cylinder as (rectangular, square, triangular, diamond.et. al) carried out to studding the fluid flow characteristic. The present work was carried out to study the effect of triangular splitter attached behind the triangular cylinder on fluid flow and heat transfer around the triangular cylinder and compared the results to the bare triangular cylinder numerically at (20≤Re≤200), (L/b=0.25, 0.5, 1, 1.5) and (S/b=0.35, 0.45).

GEOMETRICAL CONFIGURATION

The aim of the study is to investigate the behavior of fluid flow and heat transfer around triangular cylinder attached with triangular splitter placed in channel (figure-1) and the non-dimensional length of splitter (L/b=0.25, 0.5, 1, 1.5), (S/b=0.35, 0.45), (H/b=15), (Lu/b=10) and (Ld/b=20).

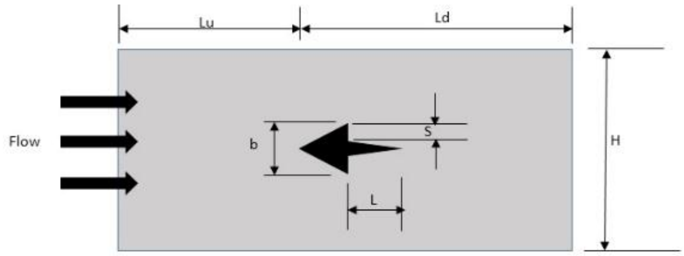

Fig. 1. Schematic diagram of the problem

GOVERNING EQUATION

For (2-D) incompressible, laminar flow across the triangular cylinder with splitter, the continuity, momentum and energy equations in x and y directions are given below Swam Srikanth [14]: -

continuity equation

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

momentum equation

$$\left.\begin{aligned} u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}&=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right]\\ u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}&=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu}{\rho}\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right]\end{aligned}\right\} \quad (2)$$

energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{1}{\alpha}+\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right] \ldots\ldots\ldots \quad (3)$$

The properties of the streaming fluid and heating are depending on the Reynolds number ($Re=\frac{\rho u b}{\mu}$), ($Nu=\frac{hb}{k}$) and ($Cd=\frac{F}{0.5\rho U^2 b}$).

BOUNDARY CONDITION

The B.C of this problems configuration was written as: -

- The inlet boundary: $U=U_\infty$, v=0
- The out let boundary: the pressure boundary is employed at the exit boundary with zero input of static gauge pressure

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- For walls of channel is no slip condition U=0, V=0 and constant wall temp. T_w=c.
- For cylinder and splitter the B.C is no slip condition U=0,V=0 and constant cylinder temp. T_{cy}=c. and $T_{cy}>T_w$

Numerical simulation is carried out with using C.V based on a modern CFD code ANSYS FLUENT v 16.1 (figure 2). GAMBIT has been used to generate the grid, this grid was very fine near the wall of channel, triangular cylinder and splitter. Triangular cell was used to construct the grid. In the present study, the best result obtains with number of element of grid of 88946.

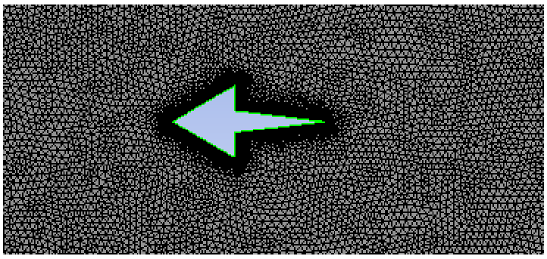

Fig. 2. Grid generation

RESULTS AND DISCUSSION

To check the validity of present numerical results with available studies, the work was done for the flow and heat transfer around bare triangular cylinder and compared with the other results. Figures- (3, 4) show that the compression of streamline at Re=100 and drag confession for present study with [10], the figure shows good agreement.

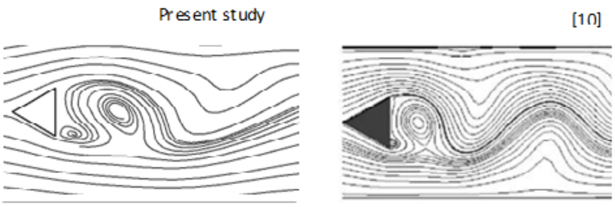

Fig. (3) streamline around triangular cylinder at Re=100 for present study and [10]

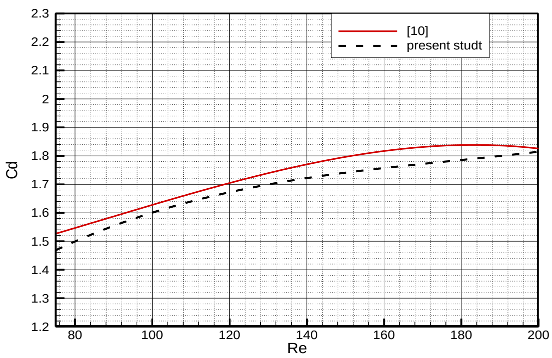

Fig. (4) drag coefficient with Reynolds number for present study and [10]

Also fig. (5) Show compares of local Nu around triangular cylinder with Arnab [10] at Re=138.8, the results show good agreement with previous result.

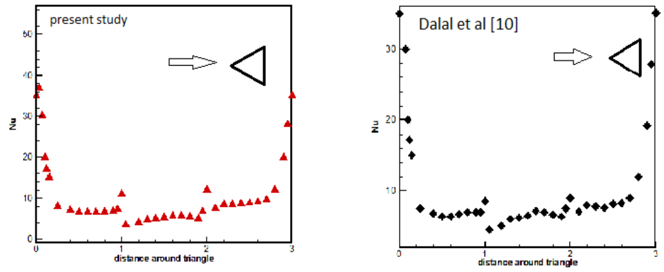

Fig. (5) local Nu around triangular cylinder for present study and [10]

In the present study the results obtain around a triangular cylinder with and without triangular splitter with different length (L) and base width (S) at (20≤Re≤200) where: -

Fig. (6 a,b) shows the temp. contours and streamline around a bare triangular cylinder with different Re, where Figure-(6 a) shows the temp. contour and the hot region have been obtained around the cylinder and maximum hot region be at rear cylinder due to the separation and recirculation of hot fluid and when increasing Re the thickness of this region decreases due to increasing the velocity of fluid ,that lead to sweeping the heat from the cylinder. Figure (6, b) shows the streamline around the cylinder where the figure shows the vortex behind the cylinder. At (Re=40) the vortex was symmetric and above this value, the alternate shedding and Von Karman vortex street will be appearing.

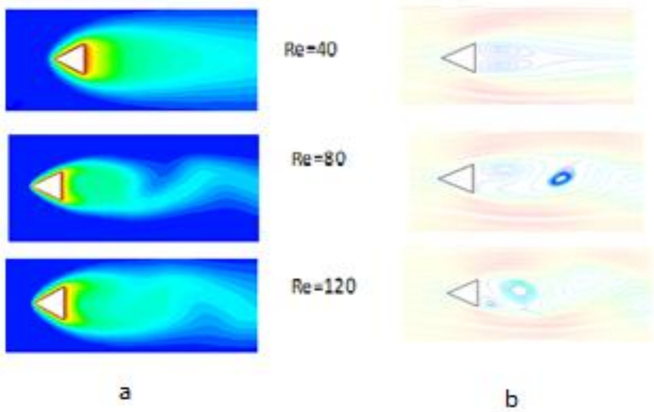

Fig. (6 a, b) temperature contours and streamline for bare triangular cylinder at different Re

Temperature contours and streamlines at (S/b=0.35) with different Re at all (L/b) configurations will be shown in figures (7 a, b). Where the clustering of temperature on front edge of cylinder is high . and the cold fluid removes the heat because of the front of cylinder is touching the incoming cold fluid, also the figure shows that the temperature and hot region increasing behind the triangular cylinder with splitter because of the increasing the area of cylinder with decreasing the recirculation region, the decreasing the recirculation region leading to increases heat transfer. Also the figure shows that the streamline for the same configurations. whereas presence the splitter behind the cylinder leading to delayed appearance of alternate shedding and Von Karman vortex

Also temperature contour and streamlines at (L/b=1) with different Re for all (S/b) configurations are shown in figures (8 a, b). These figures show that when (S/b) increase at the same splitter length (L/b), heat transfer will be increasing due to increases the area of cylinder and increases the sweeping of heat from cylinder and splitter. The streamlines of the same configurations can be shown in figure (8, b). The length of vortex will be increasing due to flowing the fluid near the splitter and sweeping the vortex from the surface of splitter, continues increasing Re let to appearance alternate shedding and Von Karman vortex.

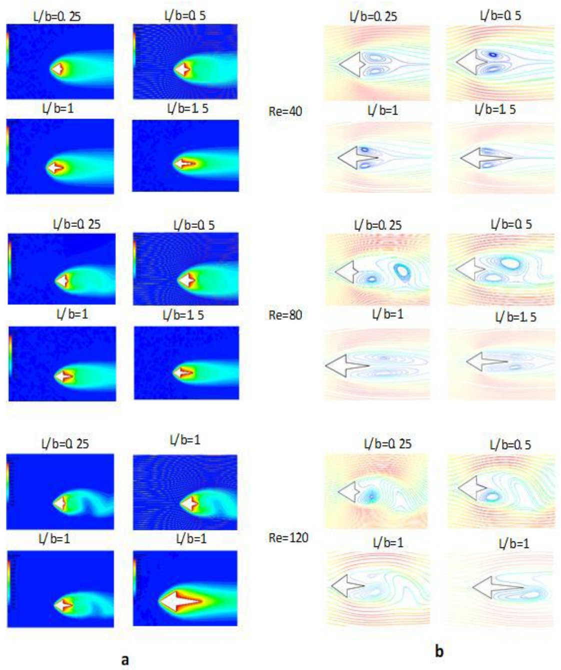

Fig. (7 a, b) temperature contours and streamline for triangular cylinder with splitter at (S/b=0.35) with different Re

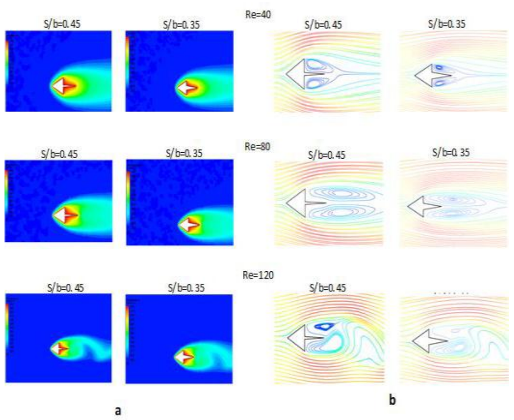

Fig. (8 a, b) temperature contours and streamline for triangular cylinder with splitter at (L/b=1) with different Re

Fig. (9) illustrates the effect of (S/b) on average Nusselt number (Nuav) at (L/b=1) and (Re=100), where (Nuav) will be increasing when (S/b) increases due to increasing the area of cylinder and decreases the separation of cold fluid.

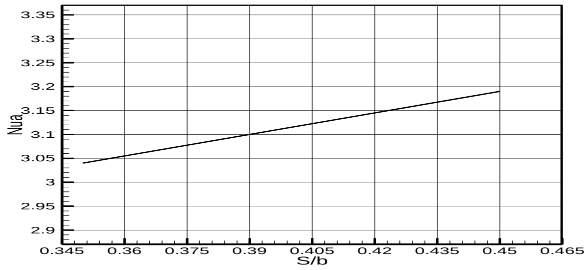

Fig. (9) average Nu with (S/b) at (L/b=1) and Re=100

Fig. (10) show the results of (Nuav) with respect to (L/b) at (Re=100) and (S/b=0.45). (Nuav) will be decreasing with increases(L/b) that mean heat transfer will be augmentation with increasing (L/b), also the result shows that any farther increasing the length of splitter will be lead to few increasing in heat transfer because of the splitter work as a fin.

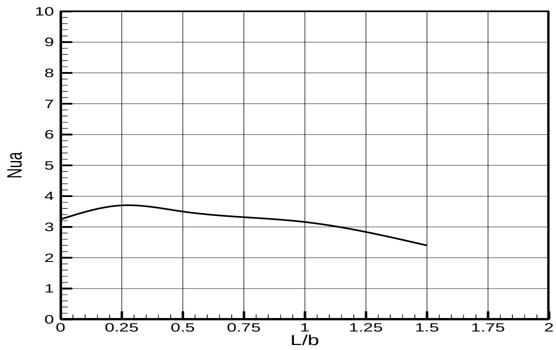

Fig. (10) average Nu with (L/b) at (S/b=0.45) and Re=100

Fig. (11) illustrates the distribution of local Nu around the triangular cylinder with and without using splitter at (L/b=0.5), (S/b=0.45) and (Re=100), the figure shows that heat transfer will be increases with using splitter.

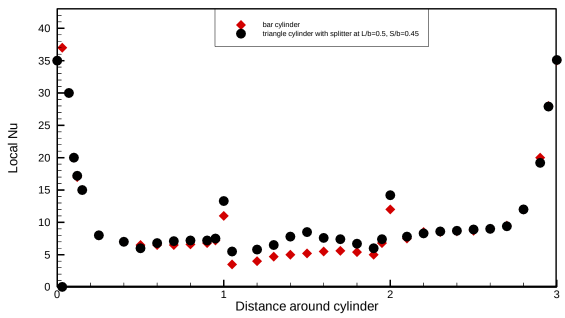

Figure (11) local Nu around the triangular cylinder without and with splitter at (L/b=0.5), (S/b=0.45) and (Re=100)

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The change of ratio of (Nuav)/(Nuavbare) with respect to Re for all (S/b) at (L/b=1) can be shown in figure- (12), this ratio increases with increasing Re and (S/b) due to increasing the area of cylinder and then the heat transfer will be enhancing. Figure (13) illustrate average (Nuav)/(Nuavbare) with respect to Re for all (L/b) at (S/b=0.45), the ratio of (Nuav)/(Nuavbare)will be increasing with increasing (L/b) for all Re due to moving the vortex to the rear of splitter and swapping heat from cylinder.

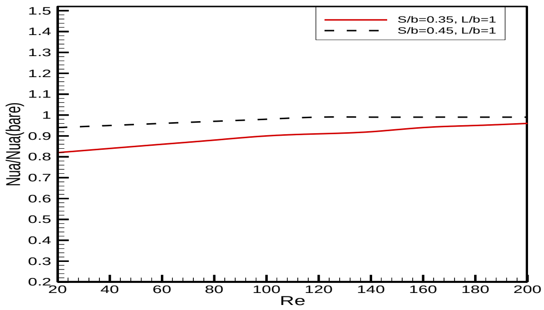

Fig. (12) average Nu with Re for all (S/b) at (L/b=1)

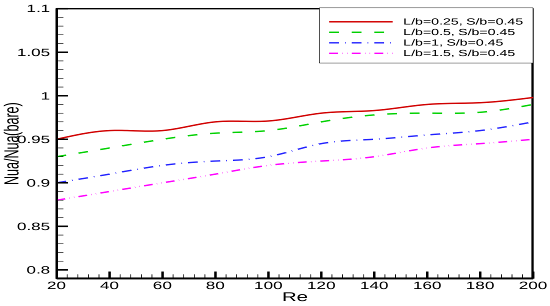

Fig. (13) average Nu with Re for all (S/b) at (L/b=1)

Fig. (14) shows the variation of (Cd/(Cdbare)) with Re at (S/b=0.45) at different (L/b), the drag decreases with increasing Re with using splitter for all (L/b) due to decreasing the vortex behind the cylinder. Also drag coefficient reduce with using splitter with different (S/b) as shown in figure (15).

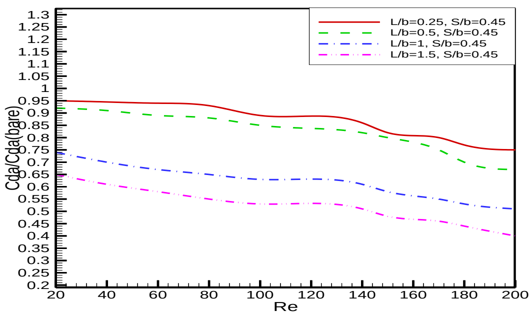

Fig. (14) average Nu with Re for all (L/b) at (S/b=0.45)

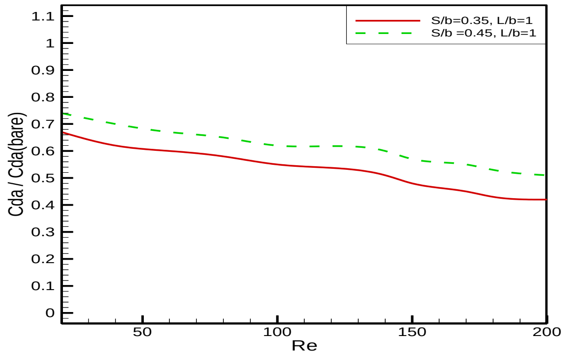

Fig. (15) average Nu with Re for all (L/b) at (S/b=0.45)

Fig. (16) shows that the critical Reynolds number dependent on splitter length (L/b), where Recr increasing with (L/b) due to controlling the separation of fluid that mean critical Reynolds number increasing with using splitter.

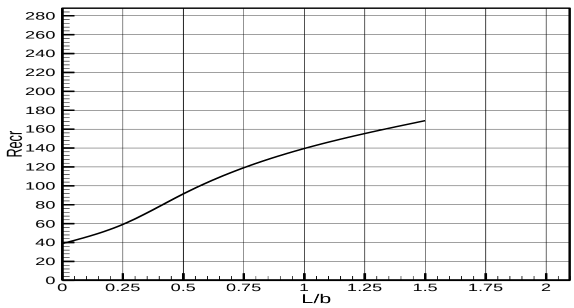

Fig. (16) critical Reynolds number with splitter length (L/b)

CONCLUSION

- Extended surface may have appreciable effect on the heat transfers and fluid flow around cylinder. The Nu and Cd around the cylinder are the two factors to be conceders in this investigation.
- In this study, a triangular cylinder with using triangular splitter behind the cylinder and the variation of splitter length (L/b=0.25, 0.5, 1, 1.5) with variation of the splitter base (S/b= 0.35, 0.45) at (20≤Re≤200).
- Using splitter enhanced heat transfer and reduced drag coefficient.
- There is an effect of splitter length (L/b) and base (S/b) on heat transfer and drag.
- Heat transfer improving with using triangular splitter by (9.5 % - 24.5 %).
- Drag coefficient reduced with using triangular splitter by (21 % -34.6 %).
- Critical Reynolds number increases with using splitter.

NOMENCLATURE

b	base of triangular cylinder, m
B.L	boundary layer
Cd	drag coefficient
D	diameter of circular cylinder, m
F	drag force, N
H	duct height, m
k	thermal conductivity, $Wm.K$
L	splitter length, m
Ld	down length, m
Lu	up length, m
Nu	Nusselt number
Nua	Nusselt number with respect to area, 1/m2
Pr	Prandtl number
r	radius, m
Re	Reynolds number
Recr	critical Reynolds number
S	splitter base, m
T	temperature, K
u	velocity in x- direction, m/sec
v	velocity in y- direction, m/sec

Greek symbols

ρ	density, $kgm3$
μ	dynamic viscosity, $kg(m.s)$

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