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The Effect of two types of Winglets on Heat Transfer and Flow Structure on Inclined Triangular Cylinder

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Abstract:

The present work concerns the study of numerical analysis on fluid flow and heat transfer from inclined triangular cylinder with using single winglet with constant wall temperature at Reynold number rang (1 to 100).in this study used two types of winglet (curved and straight). vertical distance between the cylinder and winglet was B=(b/h) = (0.8, 0.9, 1 and 1.1) with different horizontal distance S=(s/h) = (0.01, 0.03, 0.05 and 0.07) all cases at the cylinder inclined with an angles (α=3o, 6o ,9o,12o, 15o and 18o). A FLUENT 16.1 was using to compute continuity, Navier- Stokes, and energy equations by using SIMPLIC method with appropriate boundary conditions. The results indicated there is an effect for inclination of the cylinder and using a single winglet on heat transfer from the triangular cylinder. the results show that local and overall heat transfer will be improving from inclined the cylinder and with using a single winglet (curved or straight) and the maximum heat transfer be at the angle (α=5.5). curved winglet is the best for using to enhancing heat transfer. The location of the winglet near the cylinder had a major effect on heat transfer, where maximum heat transfer be at (B=0.87, S= 0.026) for curved winglet and (B=0.9, S=0.026) for straight winglet. The overall heat transfer enhanced by (12 % - 55 %) when using single winglet with inclined cylinder compared with perpendicular cylinder to the flow and using the curved shape of winglet is the best by (10%) when compared with straight winglet.
Keywords*-CFD, heat transfer, friction factor, triangle cylinder, fluent.*

I. INTRODUCTION

Fluid flow past the bodies with different shapes is an intense topic of research recently because of its applications with engineering significance as in heat exchanger, structural design and electronic cooling systems,Researchers are working hard to get to the optimum design of heat exchangers to reduce the wake area behind the cylinders and thus increase the heat transfer with minimum friction.

Improvement of heat transfer from different shapes of cylinder as a circular [1]and [2], square [3] and [4], elliptic [5] and [6],etc. was studied. These studies have been done to know the heat transfer, lift, drag and pressure drop around cylinders. As in the rest of the engineering shapes of the cylinders the triangular cylinder has many engineering application as a cooling, heat exchanger and electric. For an equilateral triangular cylinder placed in a fluid flow stream, the orientation further affects the transition, e.g. the vertex is downstream direction or facing upstream.

Many studies around triangular cylinder have been done dependent on orientation the vertex (as shown the figure (1)) experimentally and numerically.

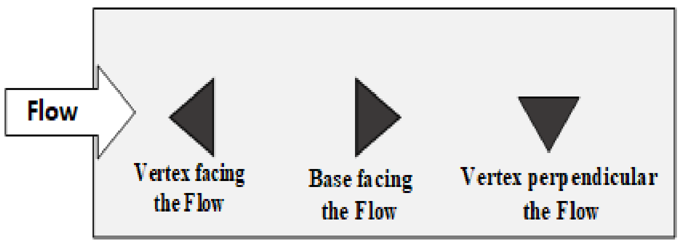

Fig. 1 Flow around triangular cylinder with different orientations

[7], [8] and [9] all examined unsteady flow over triangular cylinder (with vertex alignedalong with the direction of the oncoming flow) with a blockage

ratio of 0.067 numerically. The results reported that the value of Re_c (critical Reynolds number) in the range (36.4 to40).

[10] investigated heat transfer and flow around a triangular prism with (base to height ratio of 0.5), incarcerated in a planar channel with a blockage ratio of 0.25 at (Re = 58 – 59). They showed that the wake to lose its symmetry at (Re= 45) which was also, consistent with a basic conception that the confinement possessing a tendency to stabilize the flow[11] investigated heat transfer around horizontal triangular cylinder in cross flow of air experimentally. The blockage ratios range was (0.066 to 0.263) at Re (20000-100000) at constant heat flux. general correlations are obtained for the overall averaged Nusselt number using the cylinder length as a characteristic length and the blockage ratio as a parameter.

$$Nu_H = 0.266Re_L^{0.667}\beta^{-0.686}$$

[12] studied heat transfer and flow around triangular cylinder numerically placed in horizontal channel at Re rang (80-200) and blockage ratio (0.33-0.0833). The results show that St. number and the rms of lift coefficient increase with increasing Re and blockage ratio but Nu remained unchanged with blockage ratio. [13] studied the flow around a triangular cylinder for its vertex facing and opposing the flow, in the range of Re (30 -150). They reported the value of critical Re to be in the range (40- 42) forboth the orientations, which is larger to some extent than the previous values. [14] investigated how the symmetric planar restriction affects heat transfer and drag parameters for a triangular cylinder with its vertex oriented upstream direction, in the range of Re (1 - 80), and for a single (Pr= 0.71) and for a constant blockage ratio of (0.25). They discussed the effect of restriction as more dramatic for the time-dependent flow regime as compared to that in the steady flow regimes.

[15]have investigated how the power-law index effect on heat transfer around an isothermal-equilateral triangular cylinder when its apex faces upstream and downstream. Also, this study is restrained to the so-known steady flow regime Re≤ 30, it does cover wide range of values of the power-law index (0.2 ≤ n ≤ 1) as well as (1 ≤ Pr ≤ 100).

Some studies as [16] where they compiled the scientific researches of the trigonometric cylinder to be in order to facilitate the work for researchers and students studying this type of studies

From the above studies, for flow around triangular cylinder, result shows that heat transfer was good over two surfaces facing the flow but it bad at the base of cylinder. when the vertex of triangular cylinder perpendicular the flow only one surface has good heat transfer.

In this study we will treat with low heat transfer surfaces of the triangular cylinder perpendicular the flow by inclining the cylinder and placing two types of single winglet to increase heat transfer from the cylinder.

II. MODEL DESCRIPTION

Mathematical model

In this article, the geometrical configuration is considered as shown in figure (2). was to show the effect of inclining of triangular cylinder and putting a single winglet behind the cylinder on heat transfer. The type of winglet be either straight or curved.

The two types of winglets

*Single curvature winglets using with (case 1).

*Single rectangular winglets using with (case 2)(show figure 2).

The location of winglet in the (case 1) and (case 2) isvertical distance B=b/h= (0.8, 0.9, 1 and 1.1) with different horizontal distance S=s/h= (0.01, 0.03, 0.05 and 0.07) all cases with angle of inclined for cylinder(α= 3, 6 ,9,12, 15 and 18), L/h=100 and H/h= 25.

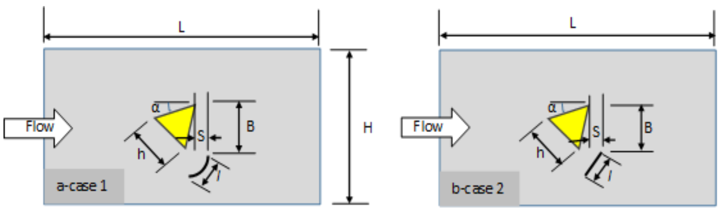

Fig. 2 the geometrical configuration of the present study

The governing eqs. for continuity, momentum and energy are presented and can be written in the Cartesian coordinate system as [17] and [18]: -

Continuity equation

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

x-momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\frac{1}{Re}(\frac{\partial 2u}{\partial x2}+\frac{\partial 2u}{\partial y2})(2)$$

y-momentum equation

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+\frac{1}{Re}(\frac{\partial 2v}{\partial x2}+\frac{\partial 2v}{\partial y2}) \qquad (3)$$

Energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{1}{Pr}(\frac{\partial 2T}{\partial x2}+\frac{\partial 2T}{\partial y2})(4)$$

Boundary conditions

The convergent criterion of 10^{-6} was found sufficiently accurate for mass and momentum equation and 10^{-9} for energy equation of this this study and the pertinent boundary conditions (B.C) in the simulation are: -

Inlet boundary

a uniform velocity normal to the inlet with zero normal velocity component

u=uinlet

v=0

T_{in}=300k

Solid Boundary

No slip condition for velocity at solid wall channel, cylinder and winglets with constant wall temperature where $T_w=T_{in}$=300k and $T_{cyl.}$=400k.

Outlet Boundary

The flow at exit is close to fully developed and assumed a zero diffusion flux for all flow variables is used

$$\frac{\partial u}{\partial x}=0 \qquad \frac{\partial v}{\partial y}=0 \qquad \frac{\partial P}{\partial x}=0$$

with the assumption of

- Steady two dimensional air flow and heat transfer
- Laminar incompressible with fully developed flow
- Constant air properties
- The thermal radiation, body force and viscose dissipation are ignoring.

The conservation equations are solved with using CFD package FLUENT 6.1 with a SIMPLIC algorithm scheme. The governing equations are solved for all such C.V the package is used to generate the grid as shown in figure (3). The grid was very fine near the walls were used to construct the grid.

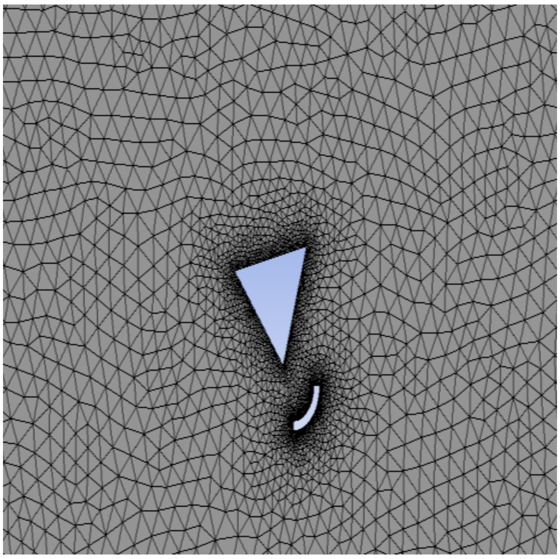

Fig. 3 grid generation for case 1

Nusselt number, the non-dimensional characteristic of heat transfer based on the base length of the cylinder (h) is

- Locally

$$Nu=\frac{h\mathrm{h}}{k}$$

- Average around the surface

$$Nuav=\frac{hav\ \mathrm{h}}{k}=\frac{1}{SA}\int_{SA}Nu\ ds$$

III. RESULTS AND DISCUSSIONS

Before discuss the results we must comparing the present study with the previous studies. Figure (4) compares the streamline for the present study with [7]. Figure (5)compared the relation between Nu and Re for the present study with [19], the results are found to be in good agreement

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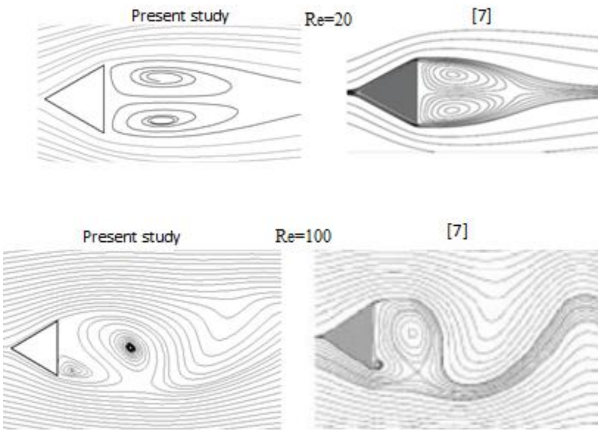

Fig. 4 streamline for flow around triangle cylinder at Re=20 and Re=100 for present study and ref.[7]

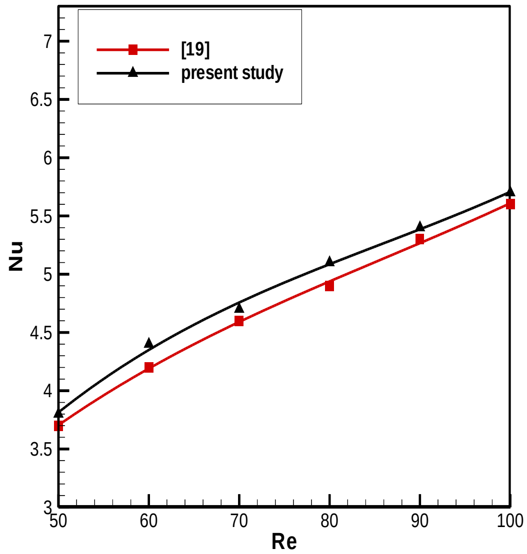

Fig. 5Nusselt number with Reynolds number for present study with reference [19]

The effect of local Nusselt number around a triangular cylinder can be shown in figure (6). It's clearly show that Nu in surface (C) is higher than the other surfaces due to the flow will be impact it and sweeping the heat from it, also it shown that Nu in surface (B) is lower because of the vortex behind the cylinder. Nu in surface (A) is between surfaces (B) and (C) due to small generated vortex when Colliding between the flow and cylinder and the flow will be moving away from cylinder and reattach by main flow. This flow and temperature distribution around a triangular cylinder is more explained in the figure (7, a and b)

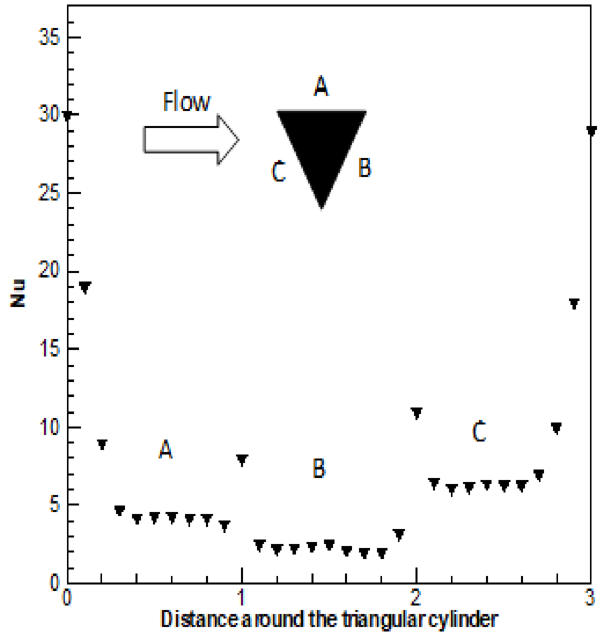

Fig.6:Nusselt number around a triangular cylinder

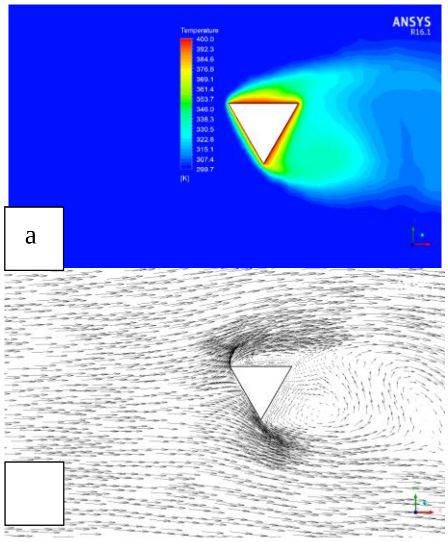

Fig. 7 a- temperature contour b- flow vector around triangular cylinder at Re=80

Figure (8) explain the effect winglet on local Nu around cylinder at (α=9^{o}), (S = 0.03) and (B=1) with using curved and straight winglet and compared the result with perpendicular cylinder without winglet.It'sclearly shown that inclination of cylinder assists to overcome the decreasing the vortex on surface (A) also using winglet keep swirls away from cylinder and curved winglet is beater from straight winglet because it has greater ability to direct the flow towards the back cylinder surface (B)

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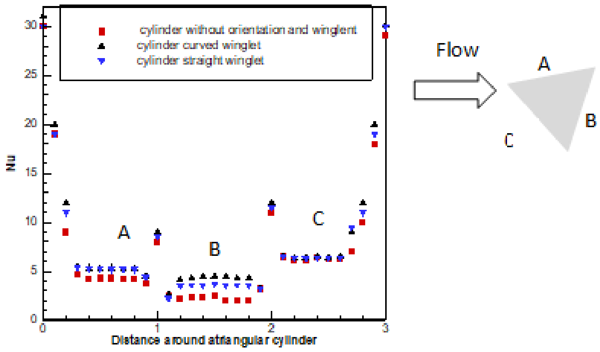

Fig.8Nusselt number around an inclined triangular cylinder at (α=9^o), (*S* = 0.03) and (B=1)

Figure (9) Represents the temperature contours and velocity vector around triangular cylinder with using curved winglet at (α=9^o, B=1 and Re=80) with different horizontal distance (S). Obviously, as the horizontal distance between winglet and a cylinder increases, the effect of winglet decreases, especiallyat (S=0.07) and the flow will be moving away from rear of cylinder.

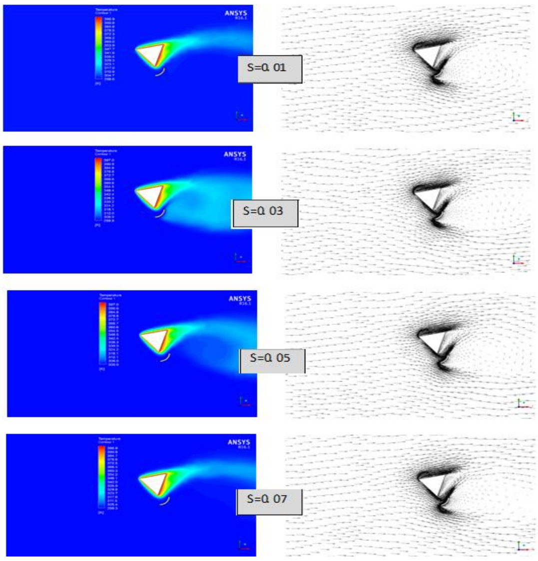

fig. 9 temp. contour and velocity vector at α=9^o, B=1 and Re=80 and different (S)

Figure (10) Represents the temperature contours and velocity vector around triangular cylinder with using curved winglet at (α=9^o, S=0.03 and Re=80) with different vertical distance (B). its shown that when (B) small the flow moving toward the cylinder strongly but this effect ended at large distance and the cylinder be as a free (without winglet) at (B≥1.1)

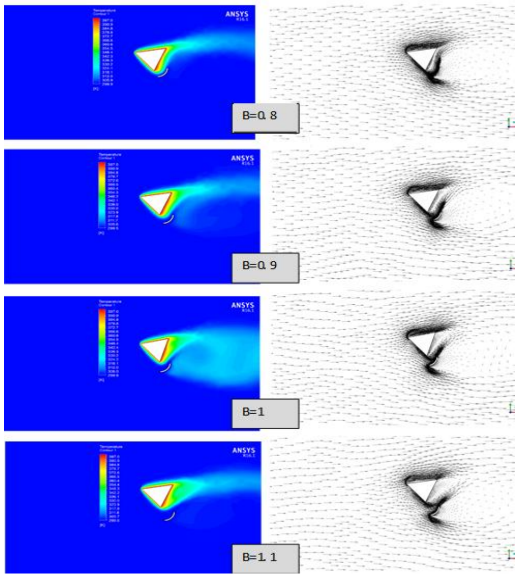

fig.10 temp. contour and velocity vector at α=9^o, S=0.3 and Re=80 with different (B)

When we check the figure 11, the effect of straight winglet on inclined cylinder are shown at (α=9^o, B=1 and Re=80) with different horizontal distances (S). its shown that the effect (as in curved winglet) is higher at small distance and the effect will be less when increases the distance due to moving the flow away from the cylinder.

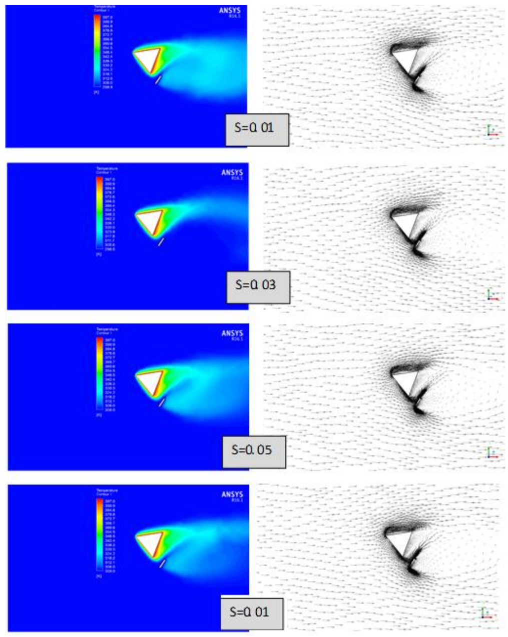

Fig. 11temp. contour and velocity vector at α=9^o, B=1 and Re=80 with different (S)

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Also, figure (12) Represents the temperature contours and velocity vector around triangular cylinder with using straight winglet α=9°, S=0.3 and Re=80 with different (B). the figure shown that when (B) is very small, the amount of heat taken from the cylinder is very large due to the sweeping the heat from the cylinder by the flow and decreasing as large distance.

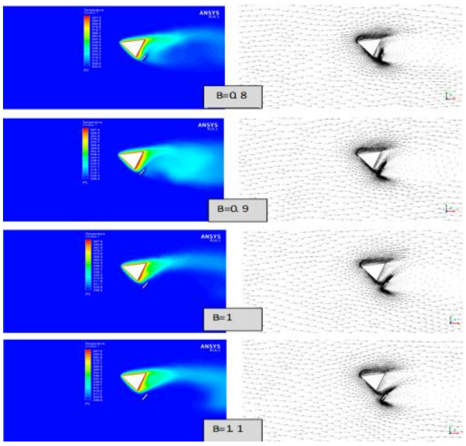

Fig. 12 temp. contour and velocity vector at α=9°, S=0.03 and Re=80 with different (S)

Figur13 shows the effect of inclination of cylinder on temperature contour and velocityvector at (B=1, S=0.03 and R=80). The increasing of inclination leads to increases the heat from the tip of cylinder because the vortices will be disappearing. When increasing the inclination, the effect of winglet will be decreasing.

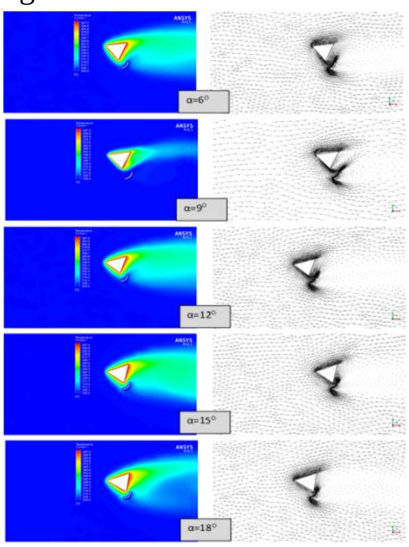

Fig.13temp. contour and velocity vector at B=1, S=0.03 and Re=80 at different (α)

Figure (14) represent the effect of Reynolds number on temp. contour and velocity vector around the triangular cylinder at (B=1, S=0.03 and α=9°). it's clear that when increases Re the sweeping of heat from the two faces facing the flow will be increasing but in the rear surface will be decreasing due moving the flow away and appearing the vortices.

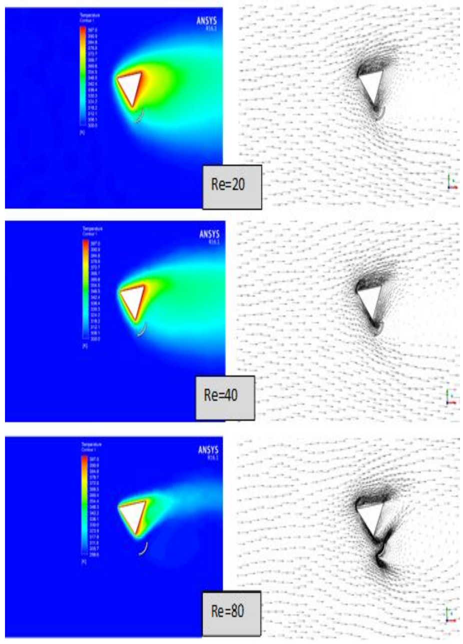

Fig. 14 temp. contour and velocity vector at B=1, S=0.03 and (α=9°) at different Re=80

Figure (15) Shows the variation of the average Nusselt number with angle of inclined of cylinder with using two types of winglets at Re=80, S=0.03 and B=1. overall heat transfer increases with inclined the cylinder and maximum heat transfer be at (α=5.5) that due to the increasing of inclination, heat transfer will be increases from top cylinder but decreasing from the rear of cylinder because of generating the vortices.

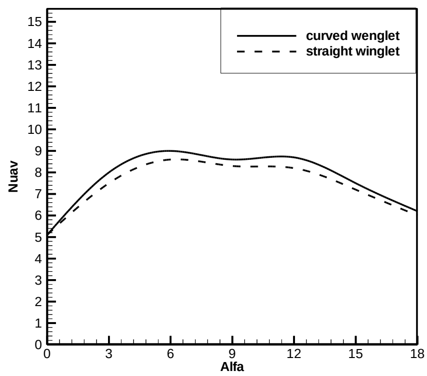

Fig. 15Nuav with angle of inclined of cylinder (α)

Figure (16) show the effect of vertical distance of winglet (B) on average heat transfer at (α=9^o and S=0.03). Heat transfer is high when the winglet be near the cylinder and guide the flow to the cylinder but when it be away from cylinder, the flow not found the enough time to sweeping the heat from rear of cylinder. Maximum heat transfer be at (B=0.87) and (B=0.9) for curved and straight winglet respectively.

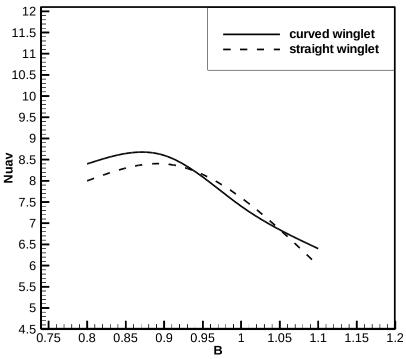

Fig. 16Nuav with vertical distance (B) at α=9^o, S=0.03 and Re=80

At the same time, horizontal distance (S) effects on overall heat transfer from cylinder as shown in figure (17) with (α=9^o and B=1). Where at small distance between cylinder and winglet, heat transfer is high and the effect of winglet ends on cylinder at the long of horizontal distance. Maximum heat transfer be at (S=0.026) for curved and straight winglets.

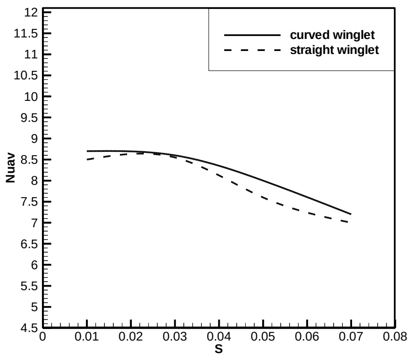

Fig. 17Nuav with horizontal distance (S) α=9^o, B=1 and Re=80

Heat transfer increases with increasing Reynolds number for all cases due to a large amount of fluid at high speed, which leads to an increase the sweeping of hot fluid near the cylinder specially with using winglet as show in in figure (18). The figure shown the compassion between the perpendicular triangular cylinder and inclination triangular cylinder at (B=1, S=0.03 and α=9^o).

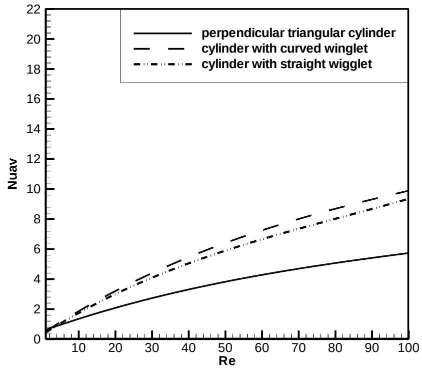

Fig. 18Nuav with Re for perpendicular triangular cylinder and inclination cylinder at (B=1, S=0.03 and α=9^o).

II. Conclusion

A 2-D numerical simulation has been performed on heat transfer and the flow around a triangular cylinder perpendicular to the flow. In this study, the effect of the inclined of the cylinder with using single winglet on heat transfer and flow structure. The commercial CFD package FLUENT 16.1 was used for modeling and CFD analysis in the present work. The horizontal and vertical distance between the cylinder and winglet was changing as S=(s/h) = (0.01, 0.03, 0.05 and 0.07) and B=(b/h) = (0.8, 0.9, 1 and 1.1) respectively. Also, the inclination of cylinder changing as (α= 3^o, 6^o ,9^o,12^o, 15^o and 18^o). In the present study using two types of winglet (curved and straight) winglet. The following conclusions can be summarized as below: -

- Heat transfer improvement from triangular cylinder when inclined it at an any angle.
- Heat transfer improvement from triangular cylinder when using single winglet.
- Local heat transfer is high from the surface facing the flow. But its low at the surface behind the cylinder.
- Inclined the cylinder and using winglet displace the vortices from cylinder surfaces.
- Maximum heat transferbe at (B=0.87 and S= 0.026) for curved winglet and (B=0.9 and S=0.026) for straight winglet.

- The best inclination value of angle (α=5.5).
- Heat transfer enhanced by (12 % - 55 %) when using winglet and inclined the cylinder.
- Curved shape of winglet is the best by (10%) when compared with straight winglet.

III. Nomenclature

b	vertical distance	m
CFD	Computational Fluid Dynamics	
h	base of triangular cylinder	m
H	channel height	m
k	thermal conductivity	W / m.K
L	channel length	m
D	winglet length	m
Nu	Nusselt number	
P	Pressure	
Pa	Prprandtl number	
Re	Reynold's number	
s	horizontal distance	m
St	Straoul number	
T	temperature	k
u	x-component velocity	m / s
v	y-component velocity	m / s

Greek symbols

α	incidence angle	degree
β	blockage ratio (h/H)	

Subscripts

av	average
c	critical
cyl	cylinder
in	inlet
out	outlet
w	wall

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