EFFECT OF CORNER CUTOFFS ON FLOW AND HEAT TRANSFER AROUND SQUARE CYLINDER +

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Abstract :

The structures of wake behind a square cylinder with cutoff corner in a laminar channel flow is studied numerically. The pressure coefficient and Nusselt number were studied for Reynolds number ranging from (500 to 1500). The governing equations are solved by using finite volume method (FVM) adapted to the staggered grid. The SIMPLE algorithm is used for the velocity-pressure coupling. Effect of direction of corner cutting (in front of side, rear side and two sides), dimensions of cutting and Reynolds number on pressure drop and heat transfer were studied. The results show that the pressure drop for square cylinder with corner cutoffs for in front of and two sides decreased when compared with that for square and rear side cases cylinders by (8% - 17%). Also heat transfer increased around square cylinder with cutoffs corner for in front of and two sides when compared with square and rear side cases cylinders by (10% - 20%), also the wake area of square cylinder with cutoff corner decreases comparing with that of square cylinder.

Key wards : square cylinder, cutoffs corner, heat transfer, flow characteristics

تأثير قطع الزوايا على الجريان وانتقال الحرارة حول اسطوانة مربعة

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المستخلص:

تمت دراسة تركيب الأثر للجريان الطباقي خلف اسطوانة مربعة الشكل بقطع زوايا الاسطوانة عدديا. وقد تم دراسة معامل الضغط ورقم نسلت لمدى من تغير رقم رينولدز ضمن (500-1500). تم حل المعادلات الحاكمة باستخدام طريقة الحجوم المحددة بالاعتماد على الشبكة المتناوبة. استخدمت طريقة (SIMPLE)لربط السرع مع الضغط. تم دراسة تأثير موقع القطع(قطع زوايا الاسطوانة ن الأمام، من الخلف ومن الأمام والخلف)، رقم رينولدز وأبعاد القطع على تغير الضغط وانتقال الحرارة. أوضحت النتائج إن الهبوط بالضغط حول الاسطوانة المربعة مقطوعة الزوايا من الجهة الأمامية والجهة الخلفية للاسطوانة قليل عند مقارنتها بالاسطوانة المربعة بنسبة (8%−17%). كذلك فان انتقال الحرارة يزداد حول الاسطوانة مقطوعة الزوايا من الجهة الأمامية والجهة الخلفية للاسطوانة عند مقارنتها بالاسطوانة المربعة بنسبة (10%−20%). إضافة إلى ذلك فان مساحة الأثر للاسطوانة مقطوعة الزوايا اقل بالمقارنة مع الاسطوانة مربعة الشكل.

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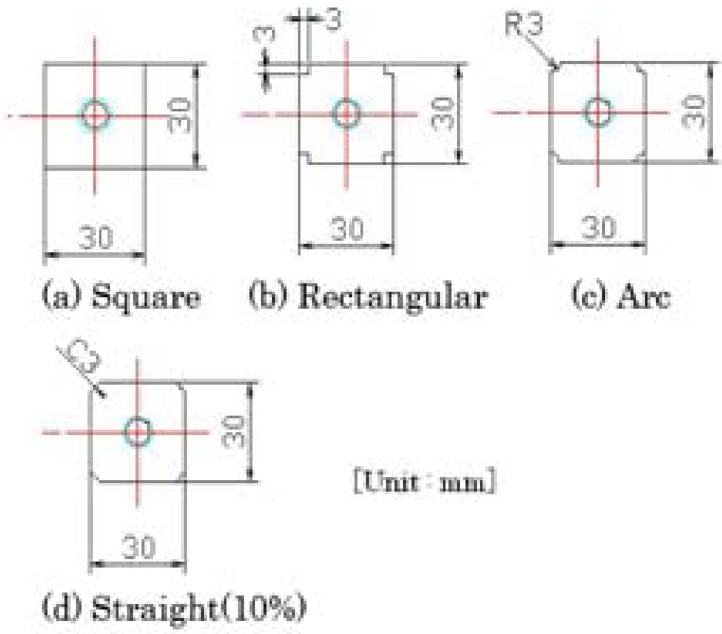
Nomenclature :

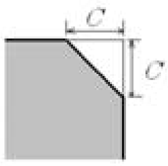
C	strait chamfer (m)
d	side length of the square cylinder (m)
Cp	pressure coefficient
FVM	finite volume method
h	heat transfer coefficient ($W/m^2.K$)
k	thermal conductivity (W/m. K)
N-S	Naveir-Stoke equation
Nu	Nusselt number
P_o	stagnation pressure (N/m^2)
Pr	Prandtl number
P_θ	local pressure (N/m^2)
Re	Reynolds number
S_Φ	source term
T	temperature (K)
T_b	bulk temperature (K)
u	velocity in x-direction (m/s)
v	velocity in y-direction (m/s)
ρ	density (kg/m^3)
μ	viscosity (Ns/m)
Γ	diffusivity
Φ	general variable
ξ, η	General coordinates

Introduction :

The force convection heat transfer and flow around bluff bodies has wide engineering applications such as heat exchangers, space heating, cooling tower and power generators. The most striking phenomenon during the flow past bluff body is generation of complex structures. The force convection heat transfer and the resulting thermal field is dictated by this complex flow.

Numerous attempts have been made for modeling the fluid flow and heat transfer over single circular cylinder as [1] and [2] and multiple circular cylinder as [3]. Heat transfer and flow structures around square cylinder are very complex with high pressure drop and drag coefficient and many researches to reduce the wake flow had been calculated as [4] and[5]. A square cylinder with grooves and taps was examined by [6], [7] and [8]. A square cylinder with rectangular cutoffs at its edges was examined experimentally by [9] and the effect of corner cutoffs on the flow characteristics around a square cylinder for changing chamfer shape and dimensions as in figure (1) was examined by [10].

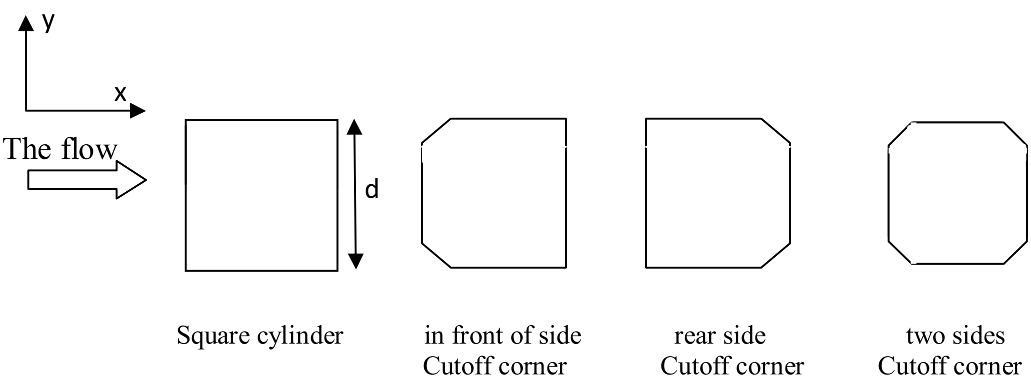


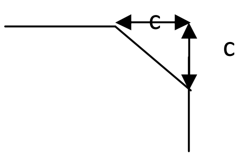


Type	Cutoff length C(mm)	C/d
Square cylinder	0	0
C1	1	0.033
C3	3	0.1
C5	5	0.167

Figure (1) the shapes and dimensions of square cylinder studied by [10]

In this study, heat transfer and pressure drop around square cylinder with cutoffs corner cylinder from one side (in front and rear sides) and two sides were examined numerically as in figure (2).





Type	C/d
C1	0.033
C2	0.1
C3	0.15

Figure (2) the shapes and dimensions of square cylinder for present studying

Governing equations, geometry and numerical details :

Figure (3) show the schematic of two dimensions body fitted grid used for present computation. This grid obtains by solving two dimensions partial differential equations (Laplas equation) [11].

$$\left.\begin{aligned}\xi_{xx}+\xi_{yy}&=P(\xi,\eta)\\ \eta_{xx}+\eta_{yy}&=Q(\xi,\eta)\end{aligned}\right\} \qquad \text{..........(1)}$$

Where P and Q used to clustering the grid near the wall to sense the velocity gradient because there is a friction between the wall and the fluid.

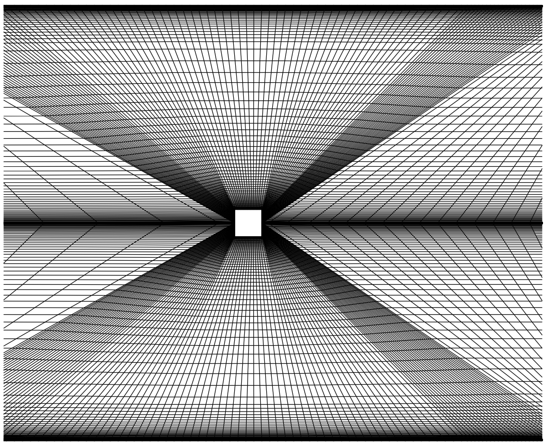


Figure (3) grid generation for square cylinder

The 2-D governing equations of mass, momentum and energy equations for steady incompressible flow can be written as following:-

Mass equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad \text{..........(.2)}$$

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\frac{\partial^2 u}{\partial y^2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+u\frac{\partial^2 v}{\partial x^2} \qquad \text{..........(3)}$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right] \qquad \text{..........(4)}$$

The above equations can be written in a general transport equation as:-

$$\frac{\partial(\rho u\phi)}{\partial x}+\frac{\partial(\rho v\phi)}{\partial y}=\frac{\partial}{\partial x}\left[\Gamma_{\phi}(\frac{\partial\phi}{\partial x})\right]+\frac{\partial}{\partial y}\left[\Gamma_{\phi}(\frac{\partial\phi}{\partial y})\right]+S_{\phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

This equation serves as a starting point for computational procedure in (FVM), by setting (Φ=1, Γ_Φ=0 and S_Φ=0) the continuity equation can be obtain, by setting (Φ=u, v, $\Gamma_\Phi=\mu$ and S_Φ contains the appropriate pressure gradient term as well as terms arising from coordinate curvature N-S equation can be obtain and by setting (Φ=T, $\Gamma_\Phi=\mu$/pr and S_Φ is contain the term arising from coordinate curvature) the energy equation can be obtain. The two terms in the left of the general transport equation (5) are convective terms, the first two terms in the right side of general transport equation (5) are diffusive terms and the last term is the source term. Equation (5) serves as a starting point for computation procedure in (FVM). The procedure for transferring this equation to general equation can be found in [12].

Boundary conditions :

The boundary conditions of the solution domain include solid walls (channel and cylinder),
The velocity on the wall equal to zero

$$u=v=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The first derivative of pressure in the direction normal to the wall equal to zero

$$\frac{\partial p}{\partial y}=0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Inlet plane

Usually at inlet boundary, all quantities have to be prescribed as following:-

$$(u)_{inlet}=u_{in}\ , \qquad (v)_{inlet}=v_{in}\ , \qquad (p)_{inlet}=p_{in}\ , \qquad (T)_{inlet}=T_{in} \ \ldots\ldots\ldots. \quad (8)$$

Outlet plane.

Always all values of dependent variables are unknown at exit boundary. This is equivalent to saying the first derivative of properties in the direction normal to the boundary is equal to zero.

$$\frac{\partial u}{\partial x}=0,\frac{\partial v}{\partial x}=0,\frac{\partial p}{\partial x}=0,\frac{\partial T}{\partial x}=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (9)$$

The boundary condition for the cylinder is constant heat flux. In the wall channel is adiabatic.

Pressure drop and heat transfer coefficients

In this study calculate local and average pressure coefficient (Cp) along the cylinder:-

$$Cp=\frac{P_{ij}-P_{O}}{0.5\rho u_{av}^{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (10)$$

And local and average Nusselt number(Nu):-

$$Nu=\frac{h_{ij}*d}{k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Where

$$h_{ij}=\frac{k}{\Delta T}*\frac{\partial T}{\partial y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\Delta T=(T_{ij}-T_{b}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

$$T_b = \sum T_{ij}/n \quad \text{...}(14)$$

n is the number of points in y-direction with different Reynolds number

$$Re = \frac{u * d}{\upsilon} \quad \text{...}(15)$$

Results and discussion:

Figure (4) shows the comparison of numerical result for pressure distribution around square cylinder with that of reference [10], the figure shows that the same procedure in two carves and shows good agreement.

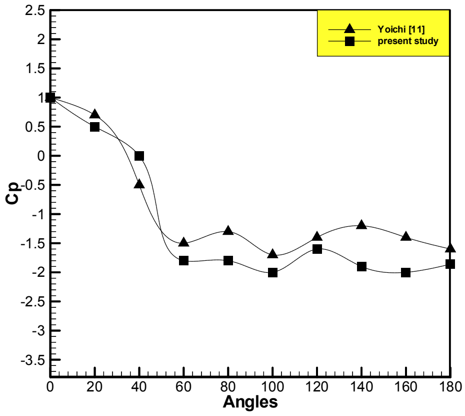
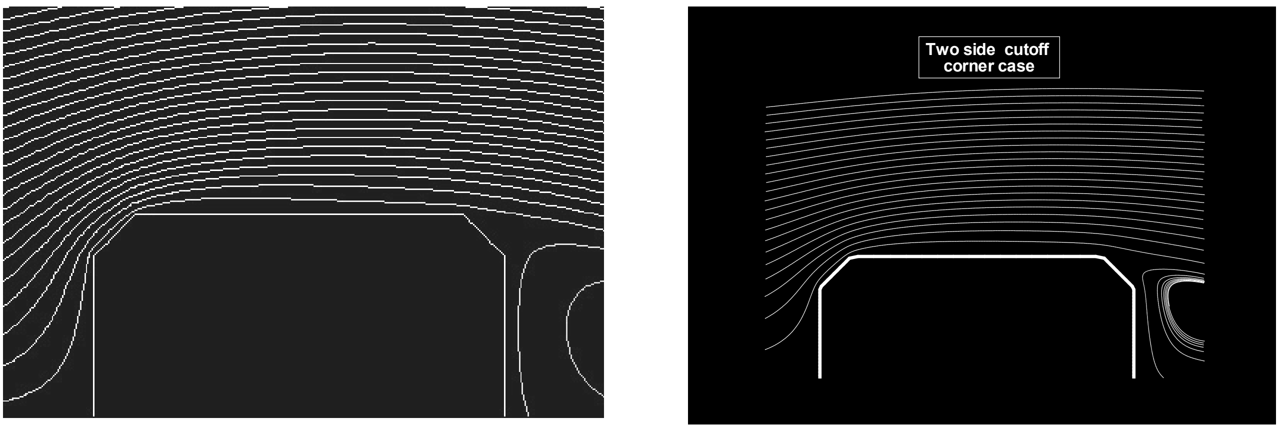


Figure (4) comparison of pressure drop over square cylinder with [10].

Also, figure (5) show the stream lines around square cylinder with cutoff corner around square cylinder at (C/d=0.1) compared to reference [10] at (Re=1000), the result show good agreement.



Reference [10]

Figure (5) stream lines around square cylinder with cutoff corner for present study with reference [10] at (c/d=0.1) and (Re=1000),

Figure (6) shown the results of stream lines around square cylinder and square cylinder with cutoff corner for (C/d=0.1) at Re=1000). It is clear that the separation area became small for cylinder with chamfer corner. The two sides case has smallest separation area and this lead to small pressure drop and small drag.

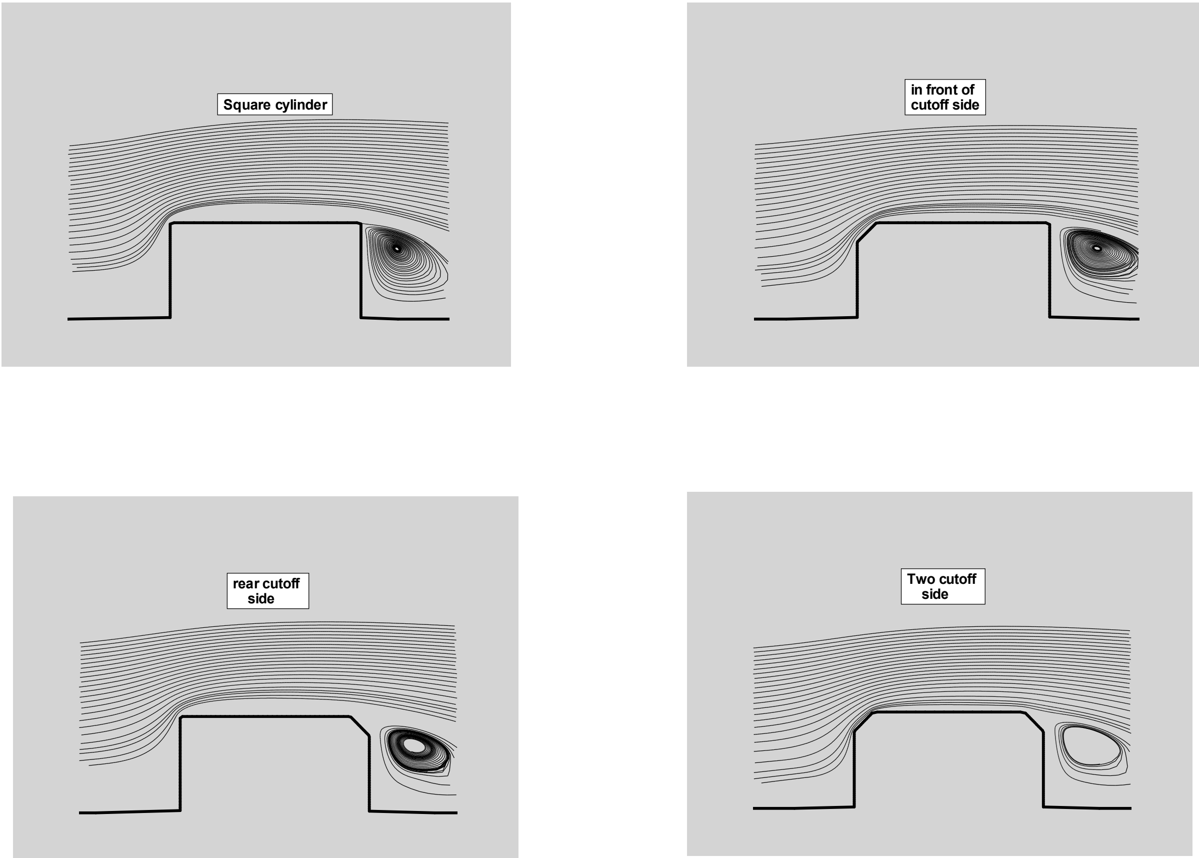


Figure (6) show the results of stream lines around square cylinder and square cylinder with cutoff corner for (c/d=0.1) at Re=1000).

Figure (7) shows the result of stream lines for two sides case with different dimension (C/d) at Re=1000. The vortex behind the cylinder is smaller with increasing dimension (C/d) this due to at smaller dimension of (C/d) the flow move away from cylinder because of high momentum and reattachment the cylinder. When increasing (C/d) the flow move near the cylinder therefore the vortex be small.

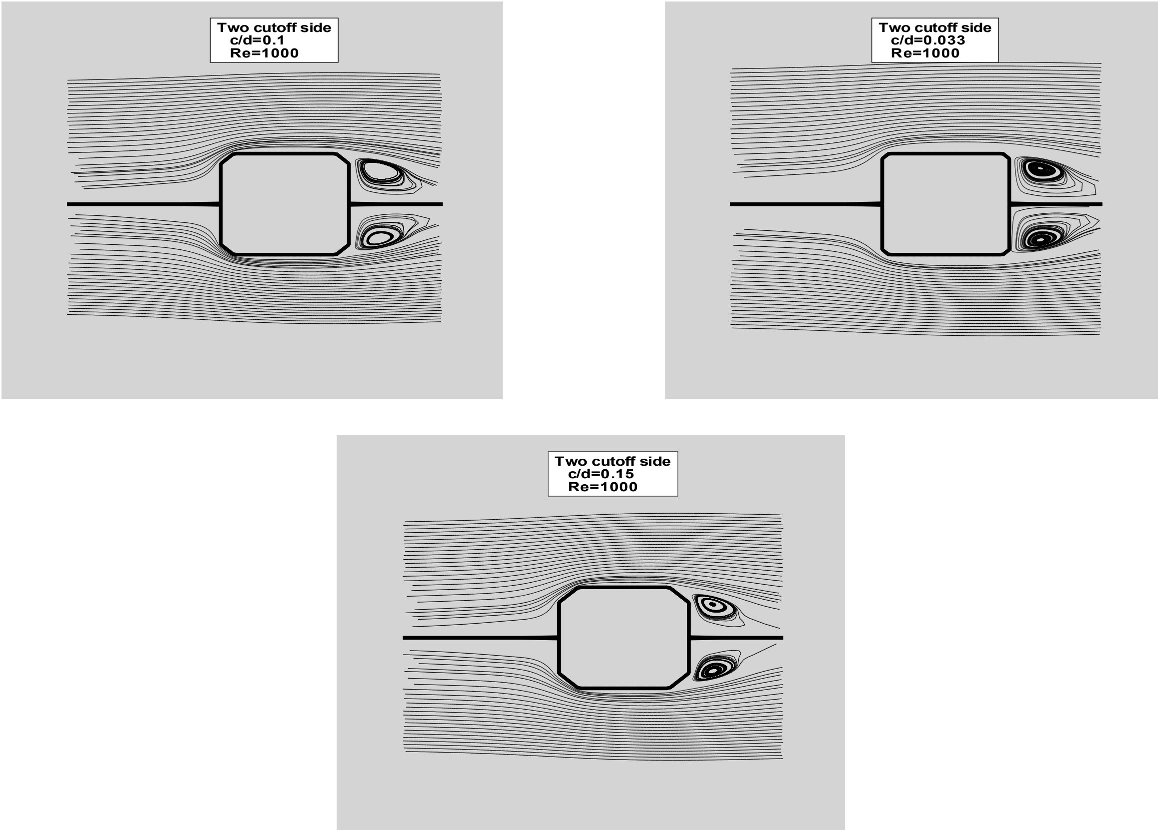


Figure (7) show the stream lines for the two sides case at deferent dimension (c/d)

Figure (8) shows the pressure distribution along square cylinder and square cylinder with cutoff corner for all cases at (C/d=1) and Re=1000. The results show that the pressure coefficient for square cylinder and square cylinder with rear side cutoff corner is large while the other cases are small in front of cylinder (0°- ~60°). The pressure coefficient behind the square cylinder of rear and two sides cutoff corner case is large.

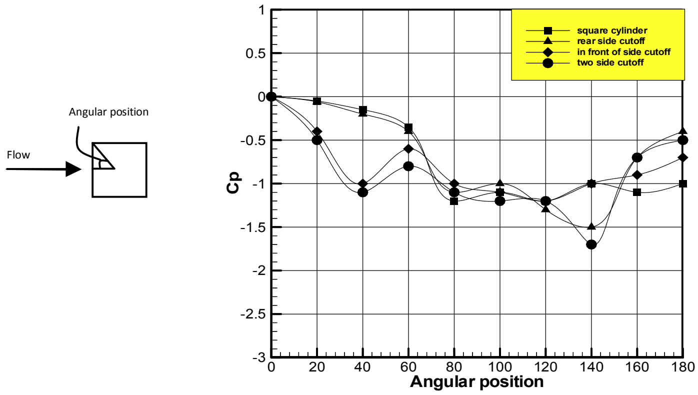


Figure (8) shows the pressure distribution along square cylinder and square cylinder with cutoff corner for all cases at (C/d=1) and Re=1000

Figure (9) shown the Nusselt number around cylinder with different chamfer and compared with square cylinder at (C/d=1) and Re=1000. The results shows that heat transfer enhancement when corner cutoff from square cylinder, this is due to decreasing the separation area and the maximum heat transfer is at square cylinder with two sides cutoff corner due to smaller separation area.

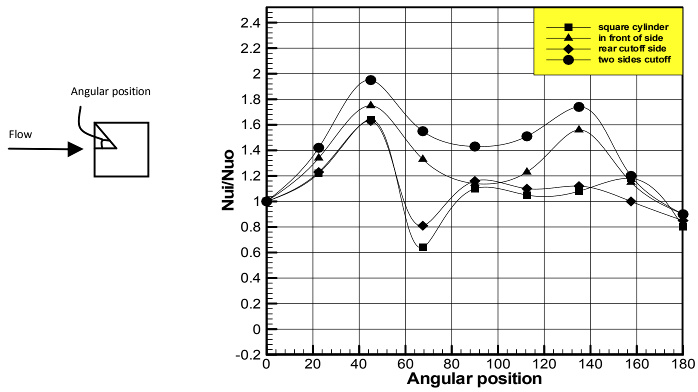


Figure (9)show the Nusselt number around cylinder with deferent chamfer and compared with square cylinder at (C/d=1) and Re=1000

Figure (10) shown the effect of Reynolds number on flow around square cylinder with in front of chamfer corner. The figure shows that when increasing Reynolds number the flow move away from cylinder due to high momentum and then reattachment the cylinder where the vortex is small.

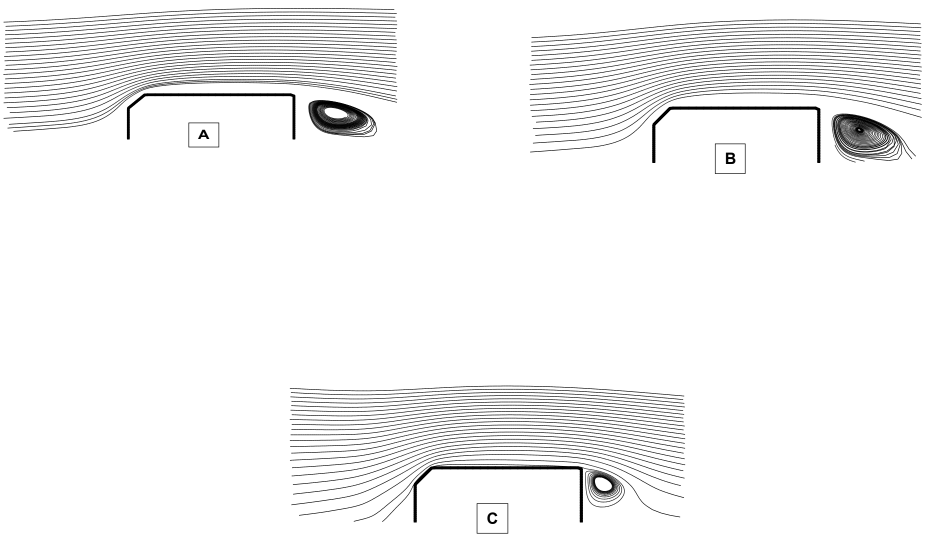


Figure (10) show the effect of Reynolds number on flow around square cylinder with in front of chamfer corner.(Re_A=540, Re_B=1000 and Re_C=1450)

Conclusions:

Fully developed laminar flow and heat transfer around square cylinder with straight cutoff corner for different cases (in front of, rear and two sides) with different dimensions of cutting (C1, C_2 and C_3) have been numerically simulated in order to examine their performances. The results show that there is an effect for cutoff corner of square cylinder on pressure distribution and heat transfer for Reynolds number range (500-1500). The results of this study was

1- The wake structure behind the cylinder was affected by the position as well as the dimensions of chamfer.

2- The separation over square cylinder as well as cylinder with rear chamfer is large.

3- Pressure coefficient for square cylinder as well as cylinder with rear chamfer is large in front of cylinders about ($\theta < 60$) and decreasing at ($\theta > 60$), this case is inverse for in front of and two sides chamfer.

4- Heat transfer increasing with cutting off corner with respect of square cylinder. The maximum heat transfer is at the case of two sides chamfer

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