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Modified Circular Cylinder Fin

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Abstract

In this work the influence of bores along circular cylinder and its rotation with respect to free stream on heat transfer rate was carried out experimentally. Three types of hollow cylinder were presented. The first one is hollow with inside diameter 15.3 mm and outside diameter 23mm. While, both the second and third cylinders have the same inside and outside diameter and provided two bores for each one with diameters 6.3 mm for the second cylinder and 7.6mm for the third one. The second and third cylinders rotate with respect to free stream at angles of (0^o, 30^o and 60^o). The free stream behaviors were observed using the smoke wind tunnel incense. Moreover, the periodic heat source was applied on these three cylinders and the temperature distributions were measured using digital thermometer. Three magnitudes of air flow velocities were presented (1.4 m/s, 1.7 m/s and 2.45 m/s) in experimental work. ANSYS software was used to predict the pressure and velocity distribution adhere the cylinder wall at maximum flow velocity (2.45 m/s). These distributions of pressure and velocity recognize the separation angles and benefit to reveal the residual mass flow inside the hollow puncher cylinder for each step. Also, the separation angles that detected depend on ANSYS program was used to quantify the average Nusselt number. The results show that the bores will increase the heat transfer dispersion especially at rotation angle 30^o. Moreover, the amount of residual mass flow inside the hollow puncher cylinder is the important parameter that used to increase the efficiency of heat dissipation. Besides, the bore with cylinder rotation angle larger than 0^o help to prevent boundary layer to be separated and kept longer attaches.

Keywords: circular cylinder, holes, separation flow, heat transfer, convection, ANSYS simulation.

Nomenclature

A: Cross section area m^2
Cp: Specific heat, J/ kg.K
D: Hole diameter m
D: Outer cylinder diameter m
h: Fluid heat transfer coefficient, W/ m^2.K
ha: average heat transfer coefficient, W/ m^2.K
k_f: Fluid thermal conductivity, W/ m.K
M: Mass kg
Min: Input mass kg
Mot: Output mass kg
Mres: Residual mass kg
Nua: Average Nusselt number $\frac{ha(\theta)D}{k_f}$
Pe_D: Peclet Number based on cylinder diameter
Re_D: Reynolds Number based on cylinder diameter
T: Temperature, degree centigrade ^oC
T1: Temperature measurement near the cylinder base ^oC.
T2: Temperature measurement near the cylinder top ^oC.
Vt: Velocity of the residual mass along cylinder m/s.

Greek symbols

θ: Angle measured from stagnation point radians.
θ1: angle from stagnation point to hole edge radian. θ_h: Angle between hole center and free stream line or rotation angle radian.
θs: Separation angle radian measured from stagnation point radian.

Subscripts

f: fluid
w: wall
∞: free stream
h: hole
in: Input
ot: output

1. Introduction

The heat transfer dissipation used in many applications which involves numerous engineering interesting methods like extended surfaces that which called fins. Where, there are so many types and shapes of fins. In this research produce a suitable way to improve a circular cylinder fin. Also, there are two main types of heat transfer conjunction with fin in most of applications, which are convection and conduction [1] and [2]. The periodic heat source behavior experimentally studied in this research and the experimental results analyzed and validate using ANSYS software. There are many applications possess periodic heat source like, electronic equipment, cylinders of air-cooled aircraft or jet engines, automatic control mechanisms, and energy storage devices [2]. Many researchers try to understand the complex pattern of mixed heat transfer from cylinder in cross flow for example; Khan et al [3] carried out the effect of parallel plates on the flow pattern and isotherm or isoflux heat transfer from circular cylinder. Later, the same researchers [4] investigated the flow and heat transfer rate from circular cylinder using the Von Karman-Pohlhausen method and deals with both isotherm and isoflux boundary conditions. Besides, the same grope Khan et al [5] after one year optimized their works where they illustrated the effect of boundary layer thickness that generated around single circular cylinder on convection heat transfer. Also, they derived suitable equations for Nu (θ) for viscous and non-viscous boundary layer. Also, they found the influence of separation angle on heat transfer coefficient. The last equations of heat transfer coefficient is modified and used in this work. Moreover, Necati A. Mahir and Zekeriya Altac [6] presented the heat transfer rate from two isothermal cylinder arranged at same line (tandem) with unsteady laminar flow. They simulated the results using Fluent (CFD package). They reported that the Nusselt number is function of angles of path around the cylinder. Besides, T.Wu and C.F. Chen [7] carried out the separation of the laminar boundary layer over circular cylinder depending on classical theory of boundary layer. They found that the augment in free stream velocity will slip down the separation point toward the flow direction. Moreover, N. Rostamy et al [8] observed the flow behavior over and behind the circular cylinder inside subsonic wind tunnel with Re_D=4.2 x 10^4. They reported that the changing of length of cylinder under their experiment will produce multiple flow situations or features in cylinder wake region appear as shedding vortex.

The objective of this work is study the augmenting of the heat transfer dissipation from circular cylinder by increasing the force and free convection influence around and inside the puncher cylinder respectively. The conventional circular cylinders that shown in figure (1) try to improve by add two circular punches with equal interval along two cylinders. Where, the each hole for first pair in cylinder (b) in figure (1) has 6.3mm diameter and 7.6mm diameter for each pair of bore in second cylinder (c). Also, all cylinders consist of hollow region with inside diameter 15.3mm and outside diameter 23mm. The experimental work was done using smoke wind tunnel to predict the flow types (laminar or turbulent) around and behind the three circular cylinders that shown in figure (1) with air flow velocity 2.45 m/s. Moreover, the angle between the air stream line (smoke scene) and hole center line changed over range (0^o-60^o) for each experimental step. Besides, the temperature distribution along each circular cylinder with same angle range experimentally measured with air flow velocities (1.4 m/s, 1.7 m/s and 2.45 m/s), respectively. The connection between conduction and convection is observed clearly in experimental work. Theoretically, the separation point for each cylinder and for each angle of cylinder rotation was predicted depends on ANSYS software. These angles were used to integrate the local heat transfer coefficient along the circumference of outer diameter for each step. The difference in mass flow at input and output in each bore was theoretical presented.

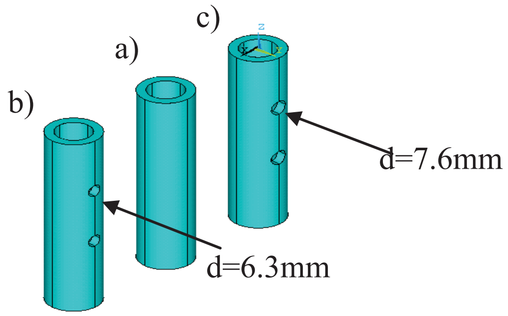

Figure (1): Three cylinder a) conventional cylinder, b) cylinder with bore diameter 6.3mm and c) cylinder with bore diameter7.6mm.

2. Theoretical improvement

Many researchers deal with enhancement of heat transfer from circular cylinder. The update of this research is predicting the separation angle over circular cylinder with air flow velocity 2.45 m/s by appealing ANSYS software. Also, these angles are used as limits of integration to calculate the average Nusselt Number Nua(θ). From reference [5] they derived a suitable equation for temperature distribution over circular cylinder without holes for non-viscous and viscous flow. For more details you can see references [3], [4] and [5].The equation of heat transfer coefficient with respect to θ for isothermal two dimensions boundary conditions presented by Khan et al [5].

$$h(\theta) = \frac{3k_f}{2D}\sqrt{\frac{1+\cos\theta}{2}}\,Pe_D^{\,1/2} \qquad \ldots(1)$$

After integration and using angles of separation from ANSYS results as limits of integration. Where, these angles indicated over a path around circular cylinder starting from stagnation or maximum pressure to point of starting negative pressure which represent the separation point as shown in figure (2).In this research used three angles of rotation between stream line and hole axis θ_h (0^o, 30^o and 60^o) for each puncher cylinder. From reference [5] the final equation of Nua(θ) was presented. The separation angles that predicted from ANSYS used as limits of integration with regardless the other effect like conduction through cylinder length or convection from cylinder wall's part that vicinity to negative values of pressure. From figure (2) and for part a) at 0° angle of rotation in a region not adhere the cylinder outer wall with Diameter 23.2mm to compensate the conditions of reference [5] and depends on reference [5], the average Nusselt number for one side and position adhere the flow small boundary layer thickness as well as high thermal boundary layer thickness is.

$$Nua(\theta) = \frac{1}{\theta_s} 3\left[\sin\left(\frac{\theta}{2}\right)\right]_{\theta 1}^{\theta s} \quad Pe_D^{\ 1/2} \qquad \ldots \qquad (2)$$

Since, the separation angle is matched. Consequently, the final Nua for this case can be written depends on reference [5]

$$Nua(\theta) = \frac{1}{\theta_s} 6\left[\sin\left(\frac{\theta}{2}\right)\right]_{\theta 1}^{\theta s} \quad Pe_D^{\ 1/2} \qquad \ldots(3)$$

After substitution the limits of integration, the final average Nusselt number Nua is

$$Nua(\theta s) = \frac{6}{\theta s}\left[\sin\left(\frac{\theta s}{2}\right) - \sin\frac{\theta 1}{2}\right] Pe_D^{\ 1/2} \qquad \ldots(4)$$

While, after rotate a puncher cylinder with angles 30° and 60°, a different angles of separation between left and right sides will recognize for each angle of rotation. The figure (2) reveals two different separation angles at right side θsr and at left side θsl in both parts b) and c) .There by; the final Nua for these cases can be abbreviate as below. Where, the limits starting from 0° until at right side θsr and at left side θsl.

$$Nua(\theta sr, \theta sl) = 3\left[\frac{1}{\theta_{sl}} \sin\left(\frac{\theta_{sl}}{2}\right) + \frac{1}{\theta_{sr}} \sin\left(\frac{\theta_{sr}}{2}\right)\right] Pe_D^{\ \frac{1}{2}} \qquad \ldots(5)$$

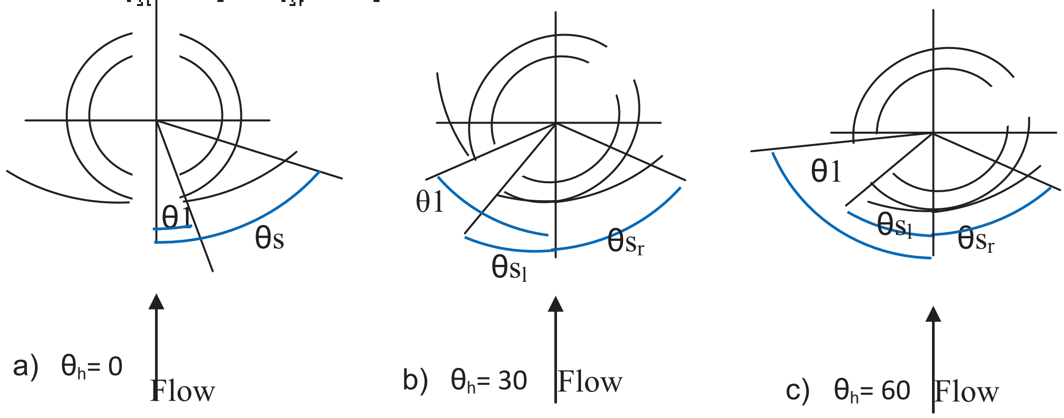

Figure (2): The angles of bore rotation with respect to flow direction.

The benefit of experimental work is verification of the type of flow (turbulent or laminar) depends on smoke scene and then used this realistic result with solving using ANSYS. Besides, the experimental work gives a good connection or mixing between the conduction and convection effect as shown in experimental results.

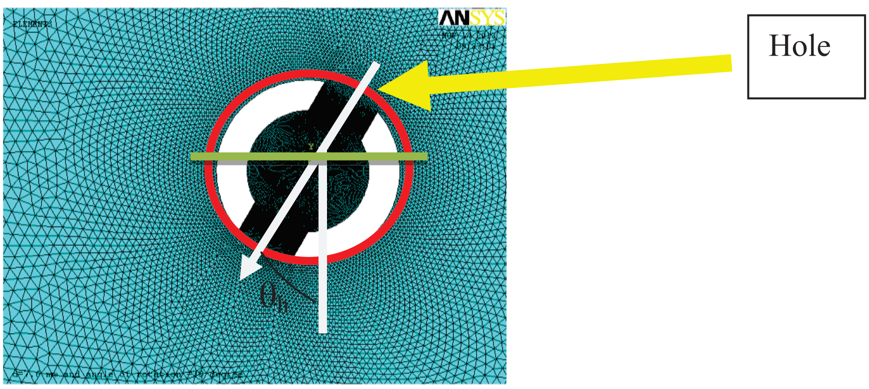

Figure (3):2D grid generation of punches cylinder where, red line represented the path at which the pressure and velocity distribution were presented to predict the angle of separation.

The conservation of mass can be used to calculate the residual mass flow rate inside the cylinder hollow using control volume procedure [1] & [2].

Mres=Min-Mot= ρA (Vin-Vot) …(3)

For two bores for each cylinder Mtotal = 2Mres

Then Vt cylinder =2Mres/ ρA_h … (4)

The conversation equation for energy that using the same control volume shown in figure (3) used to predict all energy dissipation by emphasis on the two bore influence. For more detail about the general energy conservation equation see Ref. [1] & [2].
Energy dispersion =2 Cp [(Mot (Tw-T∞) - Min T∞) +Mres (Tw-T∞)] …(5)

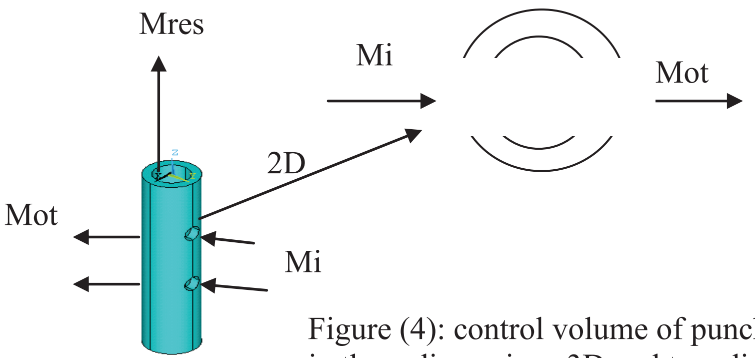

Figure (4): control volume of puncher cylinder in three dimensions 3D and two dimensions

3. Experimental device and procedure

The experimental work consists of two parts:

1) Experiment the flow pattern over and behind the three cylinders that shown in figure (1).

   The smoke wind tunnel was used to produce smoke incense. The relative movement between the smoke stream lines and the effect of cylinder on flow disrupted will motivate to separate flow from cylinder surface. In order to proposed the flow type in point of view turbulent or laminar, the smoke wind tunnel results very benefit to detect this type. Consequently, ANSYS can be used in more realistic and more accurate by using corrects flow type. Then, ANSYS results can be used to find all parameters in previous article.
2) Record the variation of temperature with time along all three cylinders. Accordingly, two thermocouples were used to understand the heat progress through the cylinder by conduction and heat dissipation air flow by convection. In this part of experimental work the three cylinders heated in a periodic time of (10 sec) at different air flow velocities (1.4 m/s, 1.7m/s and 2.45m/s) using finger heater shown in figure (5). Moreover, the temperatures along the all cylinders were measured using digital thermometer shown in figure (6). Also, the cylinder that consists of two bores the angle of rotation θ_h change with values (0^o, 30^o and 60^o). In this part the mixing effect of conduction and convection will clearly appear. The focusing in this work is the effect of holes and its direction with respect to flow direction on the improvement or enhancement the heat transfer rate by forced convection. Figure (7) illustrated the location of thermocouple that used to measure the temperature along cylinder.

Figure (5): Heater

Figure (6): Digital thermometer with thermocouples.

Figure (7): Thermocouple location.

4. Results and discussions

The periodic heat source is applied on three types of circular cylinder. First cylinder has hollow region with inside diameter 15.3 mm and the outside diameter 23mm. Besides, the second and third cylinders have the same inside and outside diameter with two bores for each cylinder. The diameter of the bores of second cylinder is 6.3 mm and the puncher diameter of the third one is 7.6mm. Figure (8) illustrated the three types of cylinders. As shown in this figure, there are two major types of heat transfer, conduction along the length of cylinder and

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convection by dissipation heat energy to air flow around the cylinder. The realistic changing of temperature distribution along these three cylinders that crossing air flow with time can be shown in figure (9). In figure (9) the temperature distribution depends on two thermocouples connected with digital thermometer where, T1 represent the location of first thermocouple near the cylinder base or heat source and T2 the location of thermocouple placed fare away from the cylinder base or heat source. The part a) carried out the overall heat transfer behavior along cylinder without holes. As shown in this part at low flow velocity equal to 1.4 m/s, the conduction effect is overcomes the convection effect. Besides, when the air flow increases the effect of conduction will disappear in spite of the conduction is still worked but is very low compare with forced convection effect. The enhancement of holes on heat transfer rate can be seen clearly at the other parts of figure (9). As shown in these parts when the bore diameter increase the effect of convection increase since the amount of cooled air that may be input to hollow region will increase. Also, the Augment in mass flow inside the cylinder hollow will increase the turbulent flow inside the cylinder and this will descend the boundary layer thickness and motivate the heat dissipation. On the other hand the forced convection from outer cylinder wall is still work. For reinforcement the heat transfer from puncher cylinder, the bore angle with stream line changed from 0^o, 30^o and 60^o. The figure (9) illustrated the angle 30^o is the best angle. Where, at this 30^o the amount of mass that input the hollow cylinder is large enough to reduce the cylinder temperature and the flow stay attach the outer wall of cylinder for long distance until separation point. The angle 60^o is less efficiency than 30^o so the flow still stationary inside the cylinder and the increment of separation angle is small. From experimental results the angle 30^o with bore diameter 7.6mm found is the best angle for heat transfer dissipation. Consequently, the best air flow velocity for maximum heat transfer is 2.45 m/s with bore diameter 7.6mm and at 30^o angle of rotation or hole angle. To abbreviate the results and emphasis on the bore influence on heat transfer rate the flow behavior around cylinder shown in figure (10). Figure (10) presented the experimental work with smoke wind tunnel on the three types of cylinder at air flow velocities 1.4m/s, 1.7m/s and 2.45 m/s. As shown in this figure the type is turbulent and the bore will increase the turbulent effect with increase air flow velocity and increase the cylinder bore angle. By appealing to the experimental results the turbulent flow is solely deals with at air flow velocity 2.45 m/s for all three cylinders. So, use these results as boundary condition with ANSYS software to predict angle of separation. Figure (11) obvious the velocity and pressure contour around conventional circular cylinder at parts a) and b) respectively. While part c represents the pressure distribution around the circular cylinder. As shown in this figure part c) the curve hump represent the stagnation point. Besides, the figure (12) illustrated velocity contours and pressure contours with airflow velocity 2.45m/s and hole diameter 6.3 mm with changing the angles between holes and stream lines starting 0^o, 30^o until 60^o respectively. Also, the grid generation for second cylinder with airflow velocity 2.45m/s and hole diameter 6.3 mm for three rotation angle shown in parts (c, f and i). The enhancement of the bore is very clear by presenting flow behavior around and inside the cylinder. As shown in this figure the input flow velocity to hollow region is reduce as the rotation angle increase until 60^o the input velocity approach to zero. Consequently, the amount of mass that input to cylinder is very low and as well as the residual mass is very low. So, the heat transfer inside the hollow cylinder between hot cylinder and inside air will be lower than other angles. Figure (15) presented the same figure parts of the figure (12) but the difference is the new bore diameter 7.6mm. The benefit of the bore increase diameter is very obvious in figure (15) by increasing the input mass to hollow region compare with previous figure. As shown in this figure the pressure distribution around the circular cylinder with all angles of rotation remains the same. Besides, the figures (13) and (16) represent the pressure distribution around the bath vicinity the cylinder wall at air flow velocity equal to 2.45 m/s with angle of rotation equal to (0^o, 30^o and 60^o) with 6.3 mm and 7.6 hole diameter respectively. Depends on these figures (13) and (16) the angle (0^o) represent the symmetric pressure distribution angle for both second cylinder with bore diameter 6.3 mm and third cylinder with bore diameter 7.6 mm. As shown in these figures at angle (0^o) the pressure distribution around the puncher cylinder has two symmetrical humps represent the two stagnation points just near the bore edge. Also, from these figures the pressure behavior is very clear where the pressure descending in symmetrical way to negative values or reach separation angle at zero pressure. The difference between figure (13) and (16) is the pressure values only, no behavior. Moreover, the flow in cylinder bores will prevent or reduce the boundary separation from cylinder wall. Besides, there are two different values for pressure distribution and the stagnation location between the angle of rotation 30^o and 60^o for each puncher cylinder. Although, similarity of behavior of pressure distribution around both cylinders but the cylinder with bore diameter 7.6mm have less in maximum value of pressure compare with cylinder that has hole diameter 6.3mm. Thus, when the diameter of bore increase at angle 0^o the pressure stagnation will decrease and vis versa with other angles of rotation. Besides the separation angles on both sides with angles of rotation 30^o and 60^o are different in values for each puncher cylinder and each angle of rotation as shown clearly in figure (13) and (16). The x-axis in figures (13), (16), (14) and (17) represent the distance along the circumference of outer cylinder. To prevent the confusion between distance and angle around the outer diameter of each circular cylinder, table (1) is carried out the relation between distance on x-axis and the angle that compensate. Figure (14) observed the velocity variation adhere the outer diameter of circular cylinder with 6.3mm hole diameter at air flow velocity 2.45 m/s and at hole angle that measured with respect to free stream at a) 0^o, b) 30^o and c) 60^o respectively. The same curves with different values can be shown in figure (17) compare with figure (14). From these figures the average velocity input to hollow cylinder is equal at 0^o this means no mass residual will the big difference in input and output velocity to holes at rotation angles 30^o and 60^o. Figure (18) illustrated the variation of Average Nusslet Number Nua with angle of cylinder rotation for bore diameter 6.3 mm (blue line) and 7.6 mm bore diameter (red line). As shown in this figure the Nua changing with angle of cylinder rotation for both bores diameter starting with clear difference at 0^o, and ending at equal value at 60^o. Also, by comparing this figure and figures (14) and (17) and looking for equation (5) refer to that the amount of residual mass is the main parameter that effect on the efficiency of heat transfer from puncher cylinder. This amount of mass depends massively on the angle of cylinder rotation. So, when this mass transfer increases then the energy dissipation will increase too.

Table 1: The relation between distance on x-axis and the angle that compensate

Distance x 10^{-2} m	0	0.723	1.446	2.169	2.892	3.615	4.338	5.061	5.784	6.507	7.230
Angle degree	0	36	72	108	144	180	216	252	288	324	360

5. Conclusions

The enhancement of heat transfer from circular cylinder with pair of bores and at different cylinder rotation angle was experimentally and theoretically investigated. The ANSYS program was very useful to predict the separation angles for each step as well as to predict the amount of flow velocity that input or output from holes. This value gives a good construction for amount of residual mass that flow inside cylinder hollow. This mass is very important for optimization the efficiency of heat transfer from circular cylinder. The important results can be abbreviated in the following:

1- The angle 30^o is the best angle of cylinder rotation; the reason is high input velocity with low stagnant parts of fluid inside hole. Also, the outer Nua is higher than 0^o and very closer to Nua at 60^o.
2- The amount of residual mass is the main parameter effect on heat dissipation from hollow and puncher circular cylinder.
3- The cylinder that possess bore with 7.6 mm diameter is best compare with cylinder that possess bore with 6.3 mm diameter in point of view heat dissipation.
4- The pressure distribution adhere outer circular cylinder very important to increase or decrease the residual mass in hollow puncher cylinder.
5- The flow in cylinder bores will prevent or reduce the boundary separation from cylinder wall.
6- At low flow velocity the conduction heat transfer is overcome on forced convection.
7- In order to investigate the force convection only must deals with high enough flow velocity.
8- The increasing in number of bores this will motivate to increase the heat dissipation efficiency.

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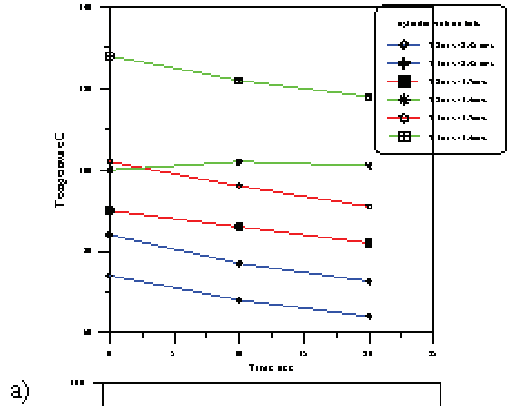


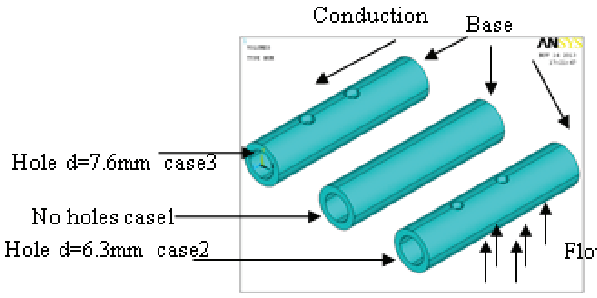


Figure (8): Problem Sketch

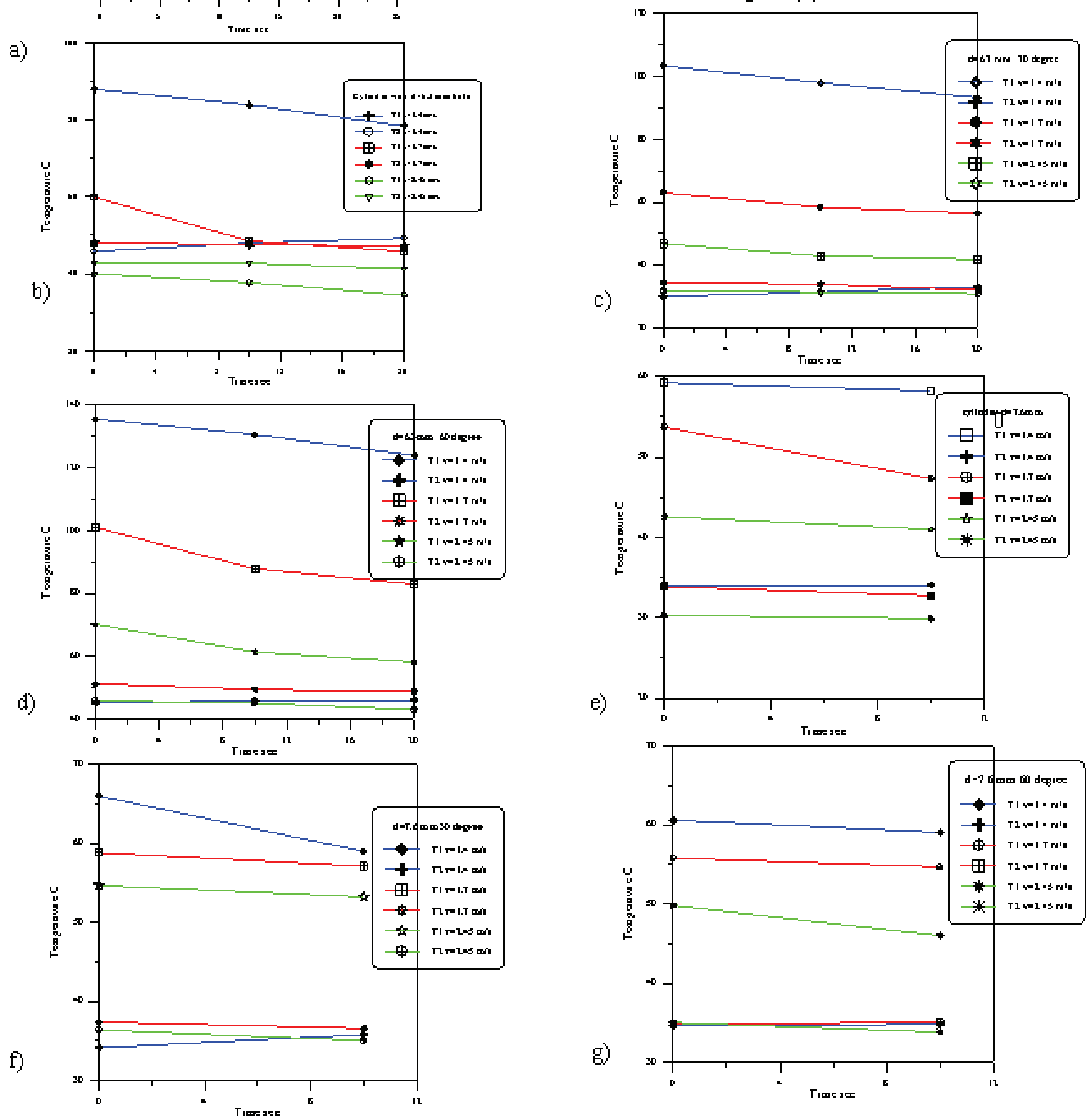
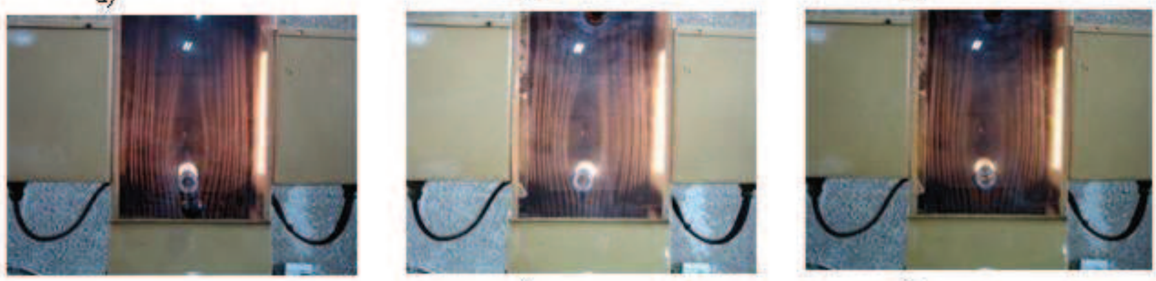
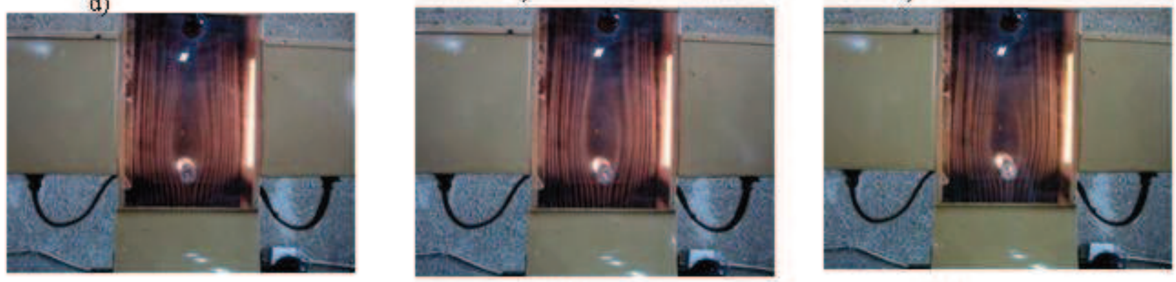


Figure (9): Experimental results, a) conventional cylinder. b, c and d) cylinder with holes d=6.3mm parallel, 30 ° and 60 ° to stream lines respectively. E, f and g) with holes d=7.3mm parallel, 30 ° and 60 ° to stream lines respectively.

a) b) c)

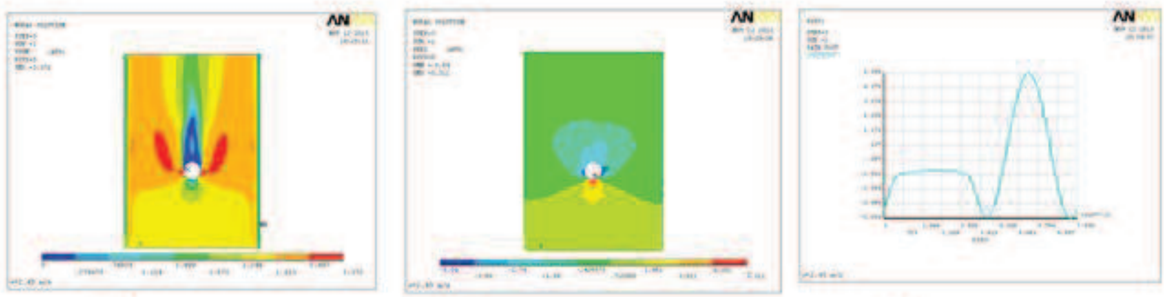


d) e) f)



g) h) i)

Figure (10): Experimental smoke wind tunnel results a, b and c conventional cylinder with airflow velocity 1.4, 1.7 and 2.45 m/s respectively, while d, e and f cylinder with two holes (d=6.3 mm) and airflow velocity 2.45m/s at 0°, 30° and 60° respectively. Compare Reference [7].



a) b) c)

Figure (11): a) velocity contour, b) pressure contour and c) grid generation with airflow velocity 2.45m/s and without holes.

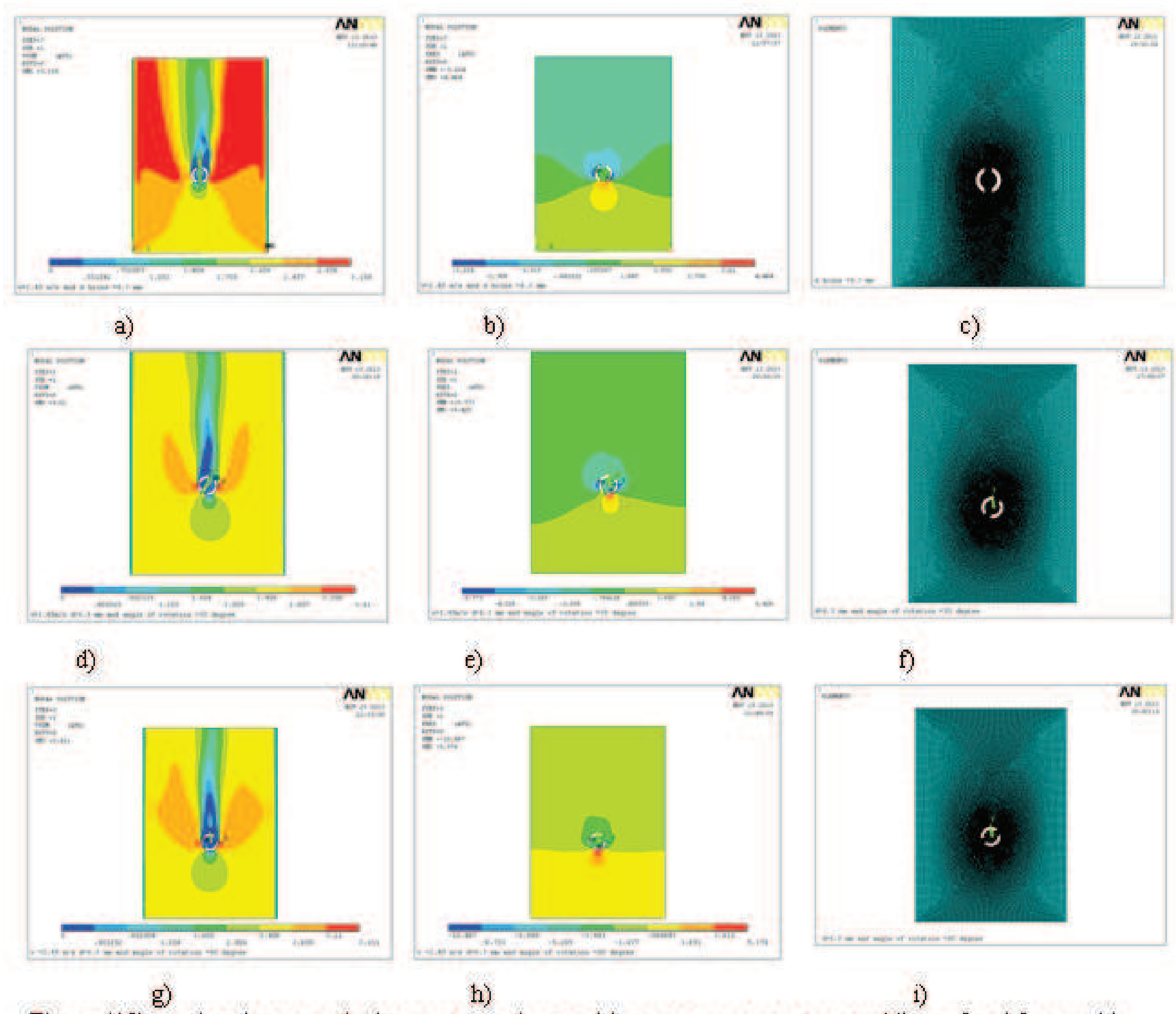


Figure (12): a, d and g are velocity contours, b, e and h are pressure contours while c, f and I are grid generation with airflow velocity 2.45m/s and hole diameter 6.3 mm at angles between holes and stream lines 0°, 30° and 60° respectively.

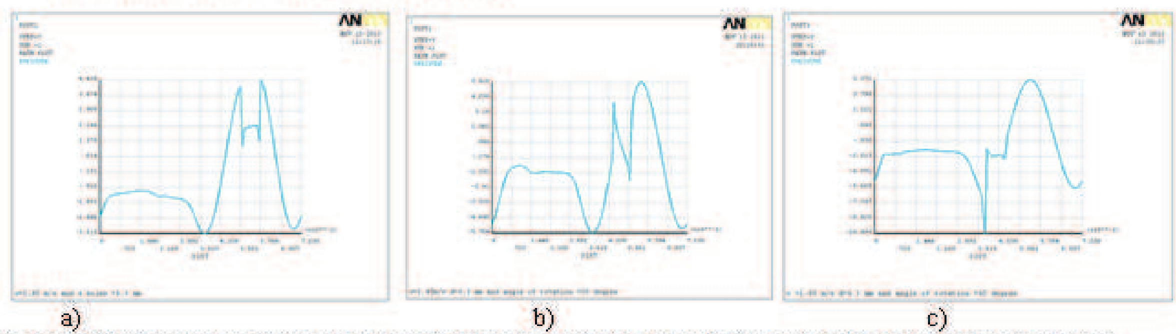


Figure (13): Pressure variation adhere outer diameter of circular cylinder with 6.3mm hole diameter at air flow velocity 2.45 m/s and at hole angle with free stream a) 0°, b) 30° and c) 60° respectively.

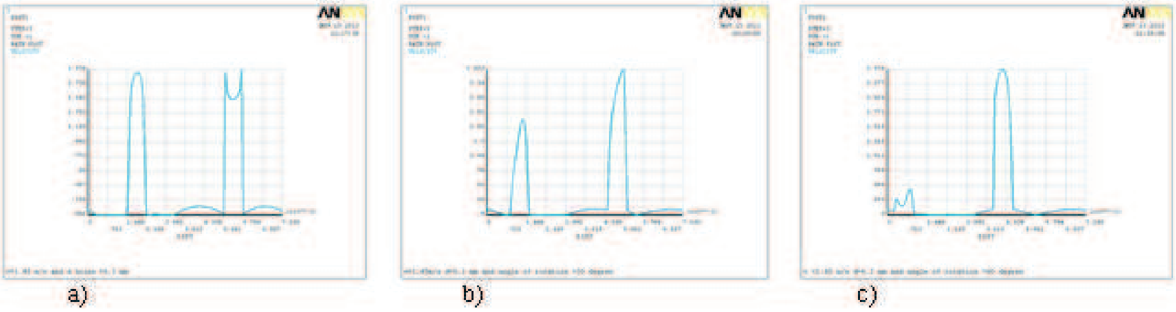


Figure (14): Velocity variation adhere outer diameter of circular cylinder with 6.3mm hole diameter at air flow velocity 2.45 m/s and at hole angle with free stream a) 0°, b) 30° and c) 60° respectively.

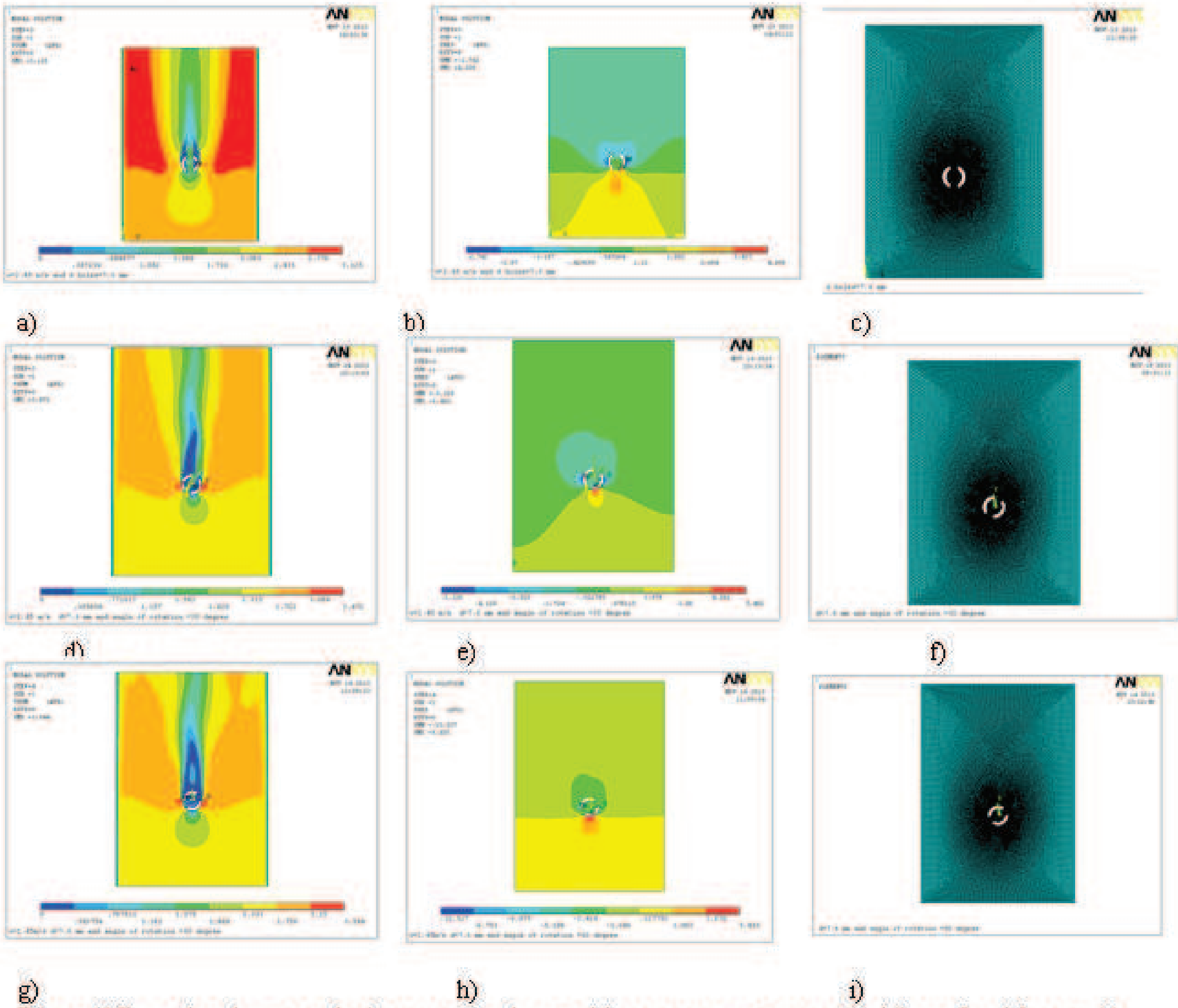
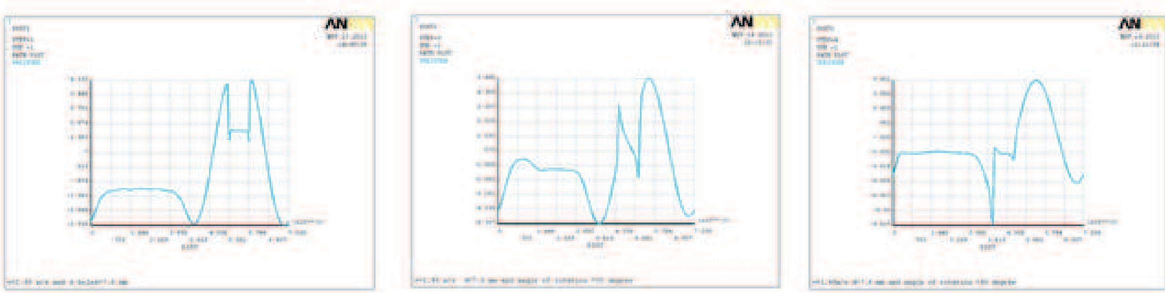
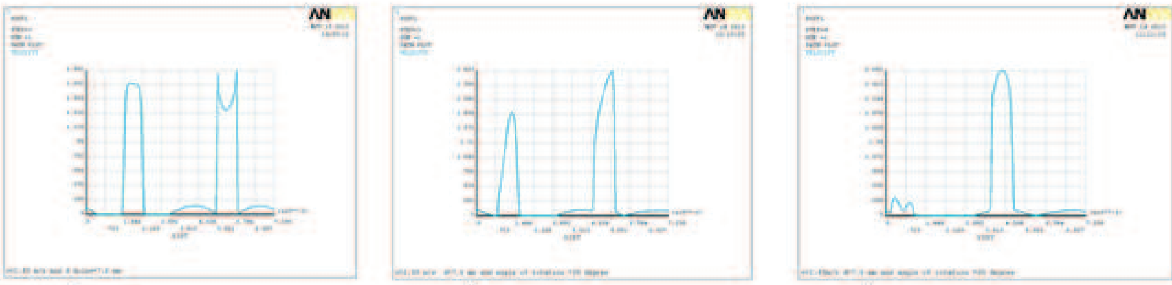


Figure (15): a, d and g are velocity contours, b, e and h are pressure contours while c, f and I are grid generation with airflow velocity 2.45m/s and hole diameter 7.6 mm at angles between holes and stream lines 0°, 30° and 60° respectively.



a) b) c)

Figure (16): Pressure variation adhere outer diameter of circular cylinder with 7.6mm hole diameter at air flow velocity 2.45 m/s and at hole angle with free stream a) 0°, b) 30° and c) 60° respectively.



a) b) c)

Figure (17): Velocity variation adhere outer diameter of circular cylinder with 7.6mm hole diameter at air flow velocity 2.45 m/s and at hole angle with free stream a) 0°, b) 30° and c) 60° respectively.

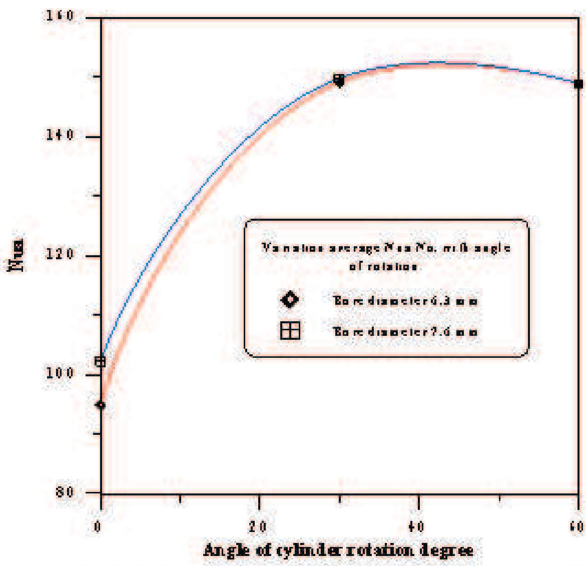


Figure (18): Variation of average Nusslet Number Nua with angle of cylinder rotation for bore diameter 7.6 mm (blue line) and 6.3 mm bore diameter (red line).