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EXPERIMENTAL INVESTIGATION OF WALL EFFECT ON DRAG COEFFICIENT OF DIFFERENT PARTICLES SHAPE MOVING IN NEWTONIAN AND NON-NEWTONIAN FLUIDS

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KEYWORDS: drag coefficient, wall effect, Newtonian fluids, non-Newtonian fluids, CFD.

ABSTRACT
The aim of this work is to study the wall effect on drag coefficient to reduce the net drag hydrodynamic force of effect finite boundaries on particle settling velocity. Experiments were conducted using plastic transparent cylinders of (40, 60, 80,100) mm outer diameter and 1520 mm length as a column for fluid container. Two types of fluids, suspension of carboxy methyl cellulose CMC (3 g of CMC in liter of water) were used as non-Newtonian fluid, water represents as Newtonian fluid. Stainless steel different shapes particles , Spheres with diameter of (11,12.5,14.5,22.5,24.5,28.5)mm cylinders with length of (8.9,13.7,19.4,18.1,24.7,38.9) mm and diameters of (10,10,10,20,20,20)mm, cube with side of(8.9,10.25,11.5,17.8,19.8,23)mm, and cone with height of(27,26.3,25.9,30,35,40) mm and diameter of (10,12.5,15,26,29.1,34.2) mm were used in the experiments. Equivalent diameter was used to evaluate the diameter for non-spherical particles. The range for diameter particle to diameter container (β) (0.118<β<0.814). Result showed that the drag coefficient increase with increase diameter ratio. Also non- Newtonian fluid having smaller wall effect than Newtonian fluid because the non-Newtonian fluid behavior as shear thinning fluid ,the flow index is less than Newtonian fluid .A CFD software ANSYS FLUENT 15 software was used for supporting the case studies.

INTRODUCTION
Different particle shapes moving in Newtonian and non-Newtonian fluid are used to study the wall effect on drag coefficient. Movement of particle through a fluid requires external force acting on a particle this force come from the difference in density between particle and fluid this mean to get the free falling for particle the density for particle is greater than the fluid used .The particle that moving in fluid subjected to three forces: gravitational force (F_G), the buoyancy force (F_B), and drag force (F_D) .It is important that the value of gravitational force is greater than the sum of the (F_B&F_D). The drag force is in parallel to the motion of particle but in the opposite direction also in this study introduce the (FW) is the wall effect on the particle defined as it is a retardation effect on the particle sedimentation in fluid movement through the presence of the walls, the particle during sedimentation moved the fluid towards the top equal to the volume of the particle volume and have the fluid movement of reverse movement of the particle thus when the wall present this lead to lower the settling velocity, Brown, Phillip P(2003). The understanding and knowing the effect of wall on drag coefficient and about the settling velocity of a particle moving in fluid Newtonian and non-Newtonian is important and necessary for different theoretical and practical application in engineering such as design of thickeners, fluidized bed equipment, falling particle viscometer, Mingzhong Li (2014). Where the suspension or settling of solid particle will occur in chemical unit operation, also used to help design solid liquid mixture, clarifiers, Daoyun Song (2011). In environmental engineering such as processes in water treatment (flocculation, sedimentation, flotation and filtration) particle capture, and deposition in air, drilling for oil and gas, geothermal drilling, Philip P .Brown (2003). It is well known that presents walls produced a retardation force effect on a particle settling in fluid and the direction upward the effect of bounded walls .the wall effect can be calculated or describe is by using the wall correction factor (FW) which can be expressed as: ($FW = \frac{V}{V_\infty}$).This expression above is the ratio of settling velocity in a bounded fluid to that in an unbounded fluid.The wall effect is depend on the ratio of particle to container diameter, R.P.Chhabra (1995). The wall effect on the motion of particle can be described in several way: the velocity ratio, the drag force ratio the viscosity ratio, Z, Lj. Arsenijevic (2010).Particle Reynolds number

is used to indicate the boundary layer around the particle is turbulent, transition, or laminar and the drag will depend on this .also it is a measure of the inertial force to viscous forces and expressed as:

$$Re = \frac{\rho_f\, v\, d}{\mu} \quad \text{for Newtonian fluid} \quad (1)$$

$$Re = \frac{\rho_f v^{2-n} d^n}{k} \quad \text{for non -Newtonian fluid} \quad (2)$$

When Re is a particle Reynolds number, ρ_f is density of fluid, v is velocity of particle, d is equivalent diameter, μ is viscosity of fluid, n is flow behavior index and k is consistency index Clift, G. J. et al (1978). The aim of this work is study the wall effect and drag coefficient for different particle shapes and sizes through different cylindrical container filled with Newtonian fluid and non –Newtonian fluid to reduce a drag hydrodynamic force for any application then compared between results.

MATHEMATICAL CORRELATION FOR EVALUATING EXPERIMENTAL RESULTS

From different study choose some correlation to use in present work:

Empirical correlation for drag coefficient and wall effect

For non-Newtonian fluid choose correlation of Kelessidis, V.C (2004)

$$CD = \frac{24}{Re}\left[1 + 0.1466\, Re^{0.378}\right] + \frac{0.44}{1+\frac{0.2635}{Re}} \quad (3)$$

This correlation for spherical particle and range (0.1<Re<10^3)

Correlation of Chhabra,R.P(1994) for non-Newtonian and non-spherical particle(Ø>0.37)

$$CD = \frac{32.5}{Re}(1 + 2.5Re^{0.2}) \quad (4)$$

Correlation of Morrison, A.F.(2013) for spherical particle in Newtonian fluid for (Re<10^6) :

$$CD = \frac{24}{Re} + \frac{2.6\left(\frac{Re}{5}\right)}{1+\left(\frac{Re}{5}\right)^{1.52}} + \frac{0.411\left(\frac{Re}{263000}\right)^{-7.94}}{1+\left(\frac{Re}{263000}\right)^{-8}} + \frac{Re^{0.8}}{461000} \quad (5)$$

Correlation of Ganser,G.H(1993) for non- spherical particle (Re>100) Newtonian fluid:

$$\frac{CD}{K_2} = \frac{24}{Rek_1k_2}\left(1 + 0.1118 + (Rek_1k_2)^{0.6567}\right) + \frac{0.4305}{1+\frac{3305}{Rek_1k_2}} \quad (6)$$

Where;

$$k_1 = \frac{1}{3} + \frac{2}{3\sqrt{\varphi}}$$

And;

$$k_2 = 10^{1.81489(-log\varphi)^{0.5743}}$$

Correlation to find the experimental wall effect

$$Fw = \frac{V}{V\infty} \quad (7)$$

V: settling velocity in bounded media found from experiment.

V_∞ : settling velocity in unbounded media.

Correlation to find the terminal velocity in unbounded medium by Ataide,H.C(1999)

$$V_{t\infty} = \left(\frac{\rho^2}{g\,\mu\,(\rho_p-\rho)}\right)^{\frac{-1}{3}}\left[\left(\frac{18}{d^{*2}}\right) + \left(\frac{0.5909}{d^{*0.5}}\right)\right]^{-1} \quad (8)$$

$$d^* = d_p\left[\frac{g\,\rho\,(\rho_p-\rho_f)}{\mu^2}\right]^{\frac{1}{3}} \quad (9)$$

d^* : Dimensionless particle diameter

Also can found by using correlation for Mingzhong.L.etal(2014)

$$u^* = \left[\left(\frac{18}{d^{*2}}\right)^{\left(\frac{0.936\, d_*+1}{(d_*+1)^{0.898}}+(0.317/d^*)^{0.449}\right)}\right]^{-1.14} \quad (10)$$

$$d^* = d_p\left[\frac{g\,\rho\,(\rho_p-\rho)}{\mu^2}\right]^{\frac{1}{3}} \quad (11)$$

USE ANSYS FLUENT 15.0 SOFTWARE

commercial package of **FLUENT 15.0 under ANSYS 15.0** software .After graphing the geometry by AUTOCAD 2014 and describe the mesh model by using ANSYS meshing 15.0 .The system geometry used in the CFD model has the dimensions :

- Fluid zone cylinder (93,75,55,35) mm diameter and 1000 mm of high
- Particle zone: different conflagration in different dimensions used to calculate experimental result for this simulation take a set of particle smaller and bigger particle from each shape.

Governing equations for simulation experimental modeling

Conservation equations of momentum and continuity for turbulent model of the flow are presented in **FLUENT** built – in solver.

The Mass Conservation (Continuity) Equation:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\, \vec{v}) = 0 \qquad (12)$$

$Where;$

$\vec{v}$: is the velocity vector.:

$$\nabla.\vec{v} = 0 \qquad (13)$$

Momentum Conservation Equations:

$$\frac{\partial \rho}{\partial t} + (\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F} \qquad (14)$$

$$\bar{\bar{\tau}} = \mu\,[(\nabla\vec{v} + \nabla\vec{v}^{T} - \frac{2}{3}\nabla.\vec{v}I \qquad (15)$$

Boundary conditions for simulation experimental modeling

1. Stationary wall apply in the column wall.
2. moving wall apply in particle surface and input the velocity of falling particle to the moving wall and the direction of it
3. Fluid zone static (v=0)

EXPERIMENTAL WORKS

Carboxy methyl cellulose (CMC) suspension was used as non-Newtonian fluid. This Suspension was prepared by used (1.5) g of CMC laboratory powder to (500) cc of tap water this amount taken after examine many amounts and this amounts give a good properties as non-Newtonian fluid behavior. The solution was mixed by a mixer to mix the required suspension for each batch for about (5) minutes. This procedure was repeated to get about (24) liters of this suspension (the size of the cylindrical columns). Fanning viscometer type OFITE [model 800] have eight speeds (600, 300, 200, 100, 60, 6, 3 and GEL rpm) was used to measure the viscosity of the non-Newtonian fluid. Density was measured by using mud balance type OFITE .Tap water used as Newtonian fluid.

The power law constants index can be calculated from the equations used by Rabia, H. (1989):

$$n = 3.32 \times \log\frac{600 \cdot rpm \cdot reading}{300 \cdot rpm \cdot reading}$$

$$K = \frac{600 \cdot rpm \cdot reading}{(1022)^{n}}$$

$$\mu_a = \frac{600 \cdot rpm \cdot reading}{2}$$

Where $n =$ Flow behavior index

$K =$ Consistency index

μ_a = Apparent viscosity

n=0.736 k= 0.182 (pa.s^n) μ_a = 15 (c.p) ρ = 1042 (Kg/m^3)

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Experimental Rig

The rig consist mainly of four transparent columns made of PVC. The columns have outer diameters of (40, 60, 80,100) mm with (1520) mm length and (2.5) mm thickness. The column was supplied with adapter end, the adapter having same size for each columns and fixed with pipe by using (PVC CEIMENT) and then closed with galvanized plug. This galvanized plug is used for drain. The four cylindrical columns was fixed well on a rigid steel structure by using clamps. The cylindrical columns kept vertically by using a water balance with bubble and vertical level ,when the bubble sited in the middle of the balance this mean that the pipe in the vertical state position this used when put the cylindrical pipes on the steel structure and fixed on it very well. The base of rigid steel structure have one Screw in each corner used for adjusting level surface .The effective length of columns (1000) mm between the top and bottom and at diameter (40,60,80,100) mm. To avoid the error of reading of settling velocity the tube was divided into three zones as first zone is inlet section having length (260mm). It is used to reach particle forces in equilibrium .Second zone used for evaluating the settling velocity having length (1000mm). The third zone having length (260 mm) is used to avoid end effect .Figure (1) show the schematic diagram of the experimental devices.

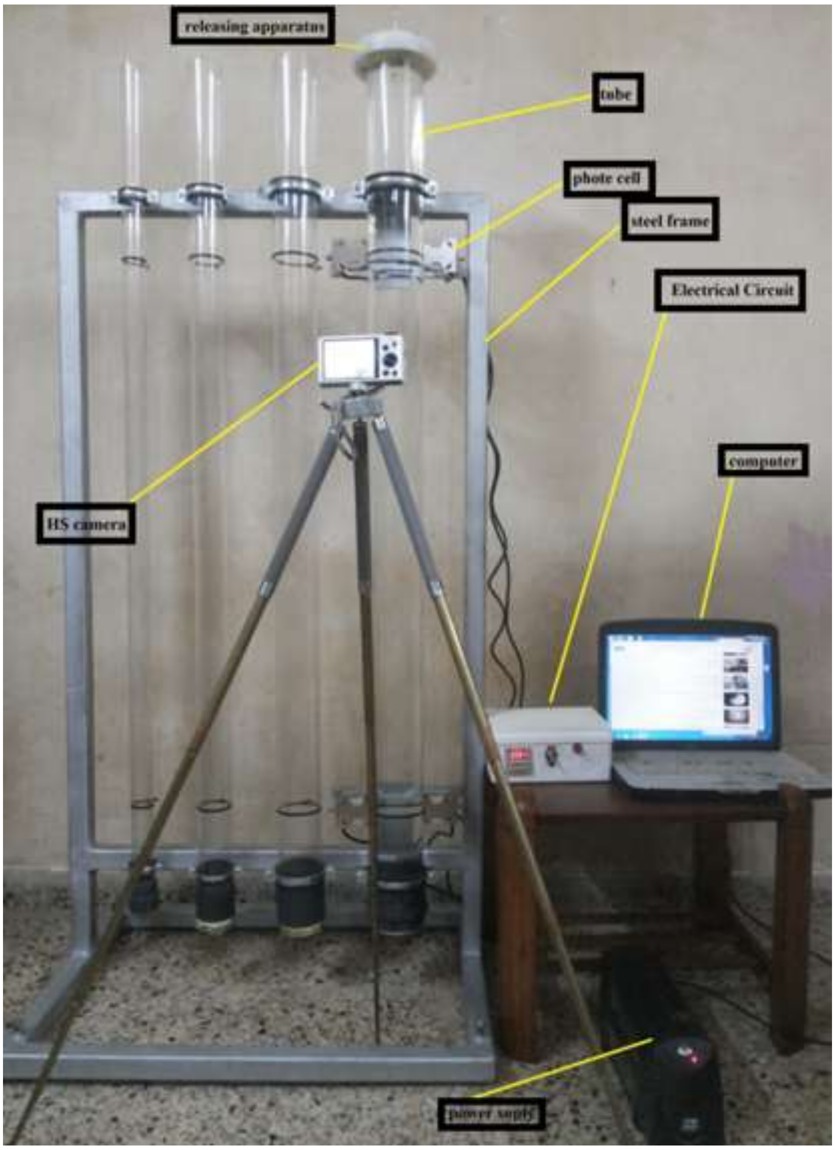


Figure (1) the experimental devices

Measuring system

Two type of measuring systems were used in this work:

Electronic measuring system (counter).

Measurement for settling velocity is directly evaluated from the time getting it by the particles travelling at known distance after travel first section. Precision of the time, electronic circuit was designed with two IR-sensor nets as show in figure (2) these two nets are measured the time of particle settling in test zone through fluid. The transmitter transmits an Infera-Red ray to receivers, when particle fell down through the column and reaches the begain of the effective part the ray will disconnect and then send (12V DC) to relay and counter start recorded time and when the particle reachs to the end of the effective part the second receiver send segment to relay to stop recorded time shown in figure (3).The method Its work looks like an interface to pick up the readings and displays them on its screen.

Figure (2) show the transmitter and receiver Infera –Red ray.

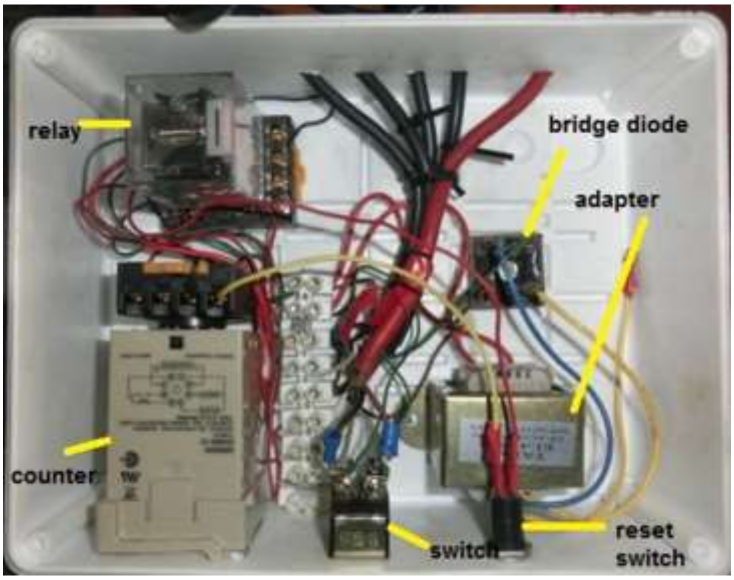


Figure (3): electronic circuit device.

High speed camera.

This method was the visualization method by using high-speed camera (1000 fps/Casio 12.5x ecilim).Using the two measuring systems on the same experiment (using water and CMC) gave the ability to calibrate the readings taken by high speed camera with those taken by counter at the same time. Always the readings of high speed camera were higher than those records by counter with about 8.197%.

RESULT AND DISCUSSION

Newtonian Fluid

Drag Coefficient Behavior

Figure (4) show that when the Reynolds number increment increase in drag coefficient the flow is turbulent and the fact that the inertial forces are dominate in this region and the viscous forces will have a small effect for this reason the increase in Reynolds will not decrease the drag coefficient, this behavior the same for four tube thus for spherical particle the result obtained a relationship between CD and Re. The drag was independent on viscous force therefore Re was independent, thus the variation in CD happen because to change in particle shape. For non-spherical particle the relationship between drag coefficient and Reynolds number depended on the sphericity.So, the drag increase while the sphericity decrease this shown for cylinder ,cube ,cone, rectangular figure (5)up to(8). This mean that the non- spherical particles for smaller sphericity having higher value for drag coefficient because the unstable for particle during settling and the orientation change the projected area for settling. From all the above the drag coefficient depends on the particle shapes, clearly depends on sphericity and did not depend on the Re because the flow is in turbulent region.

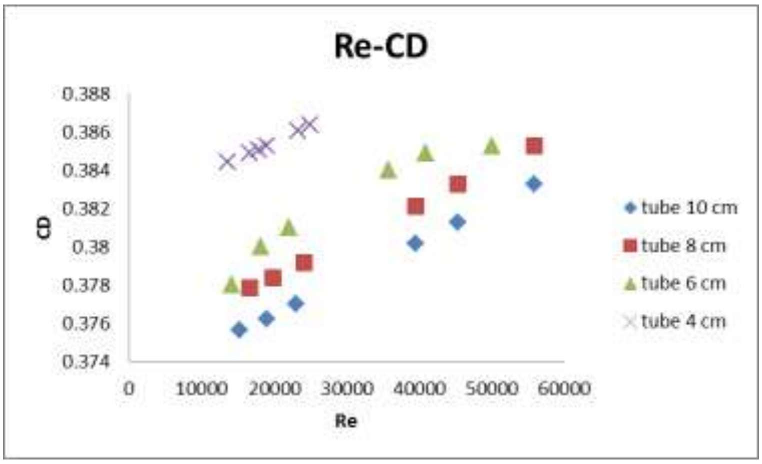


Figure (4): Relationship of (CD-Re) for falling sphere in water

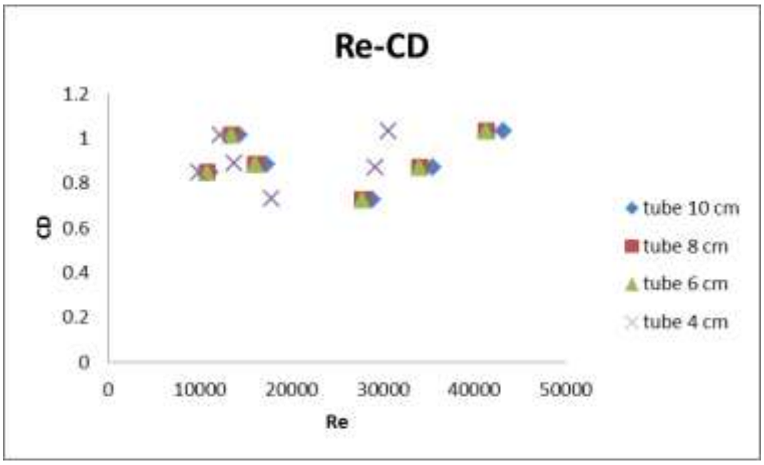


Figure (5): Relationship of (CD-Re) for falling cylinder in water

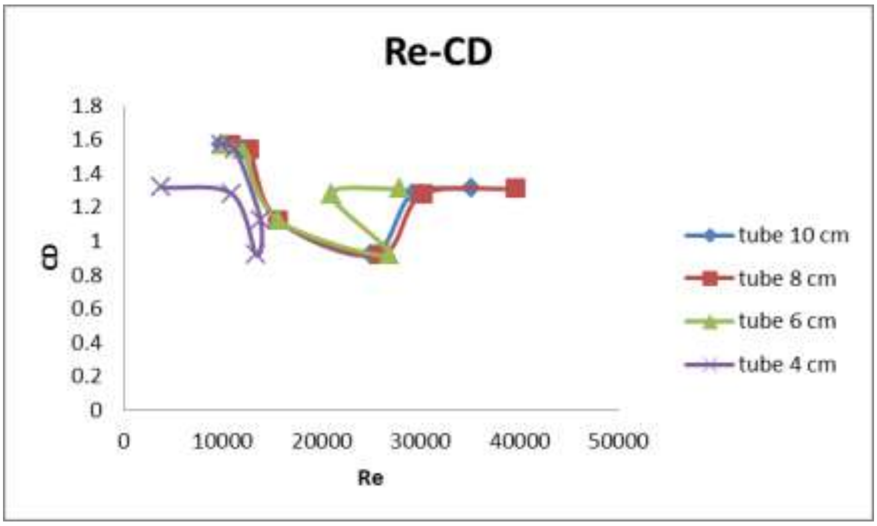


Figure (6): Relationship of (CD-Re) for falling cone in water

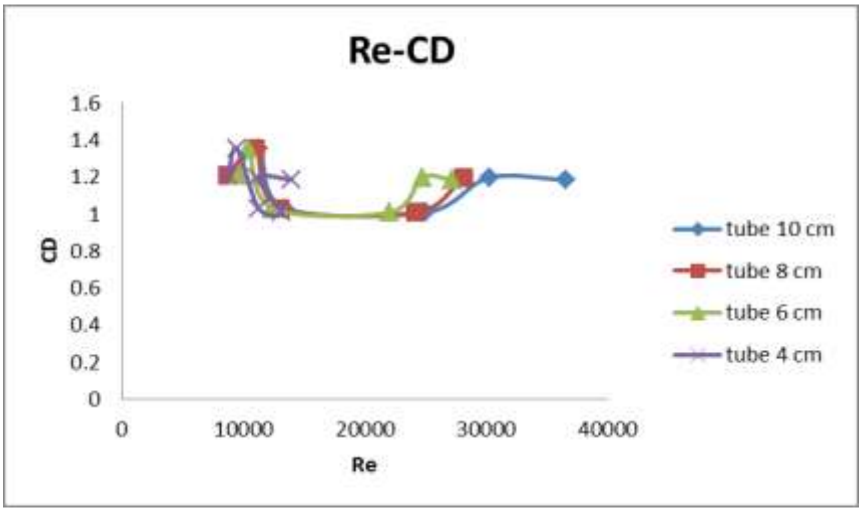


Figure (7): relationship of (CD-Re) for falling cube in water

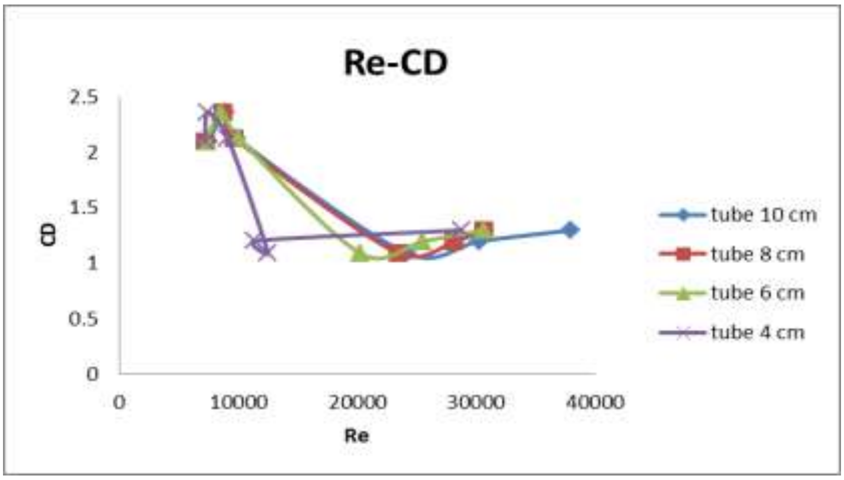


Figure (8): Relationship of (CD-Re) for falling rectangular in water

The Effect for Container Diameter on Drag Coefficient in Newtonian Fluid

Figures (9) up to (13) show the value for drag coefficient for the same particle in the four tubes. The drag coefficient increase with increasing Reynolds number but this increasing is not significant or approximately constant because the flow for particle in four tubes turbulent in this case the inertial force has highly effect in this region and the viscous force will have small effect, thus the drag independent on viscous force and therefore the Reynolds number independent in this zone. The variation in drag coefficient occurred only in a response to change in diameter ratio.

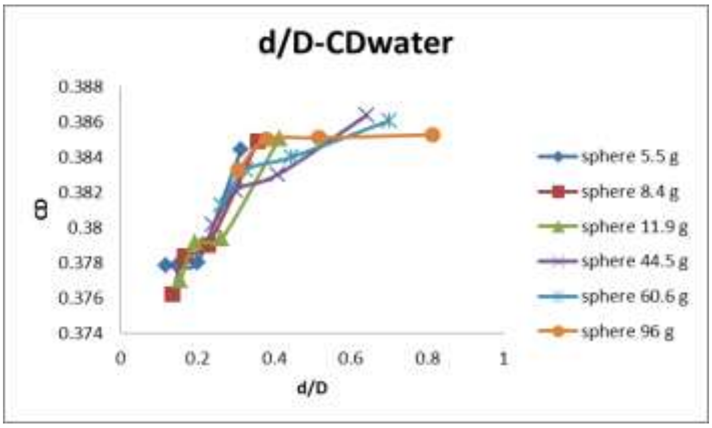


Figure (9): Relationship between (CD-d/D) for falling sphere in water

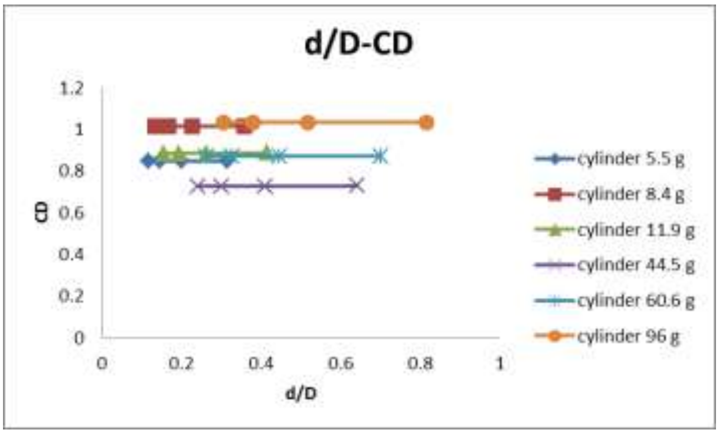


Figure (10): Relationship between (CD-d/D) for falling cylinder in water

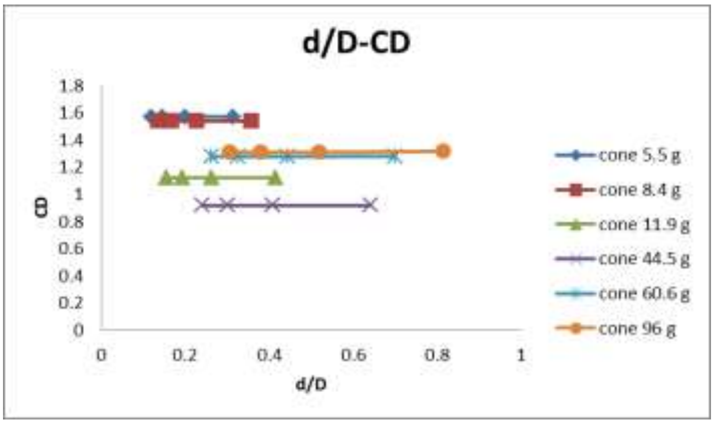


Figure (11): Relationship between (CD-d/D) for falling cone in water

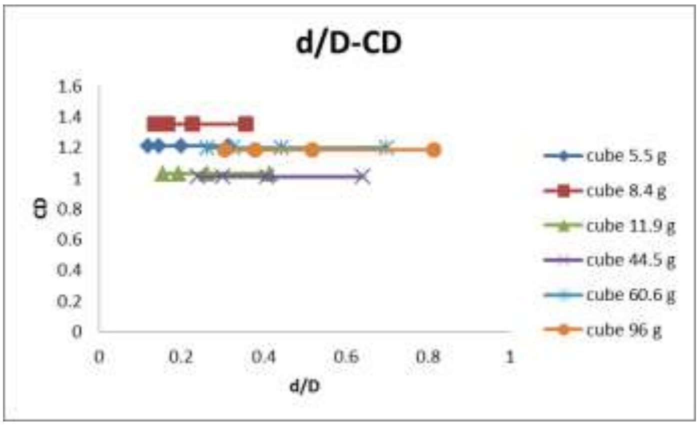


Figure (12): Relationship between (CD-d/D) for falling cube in water

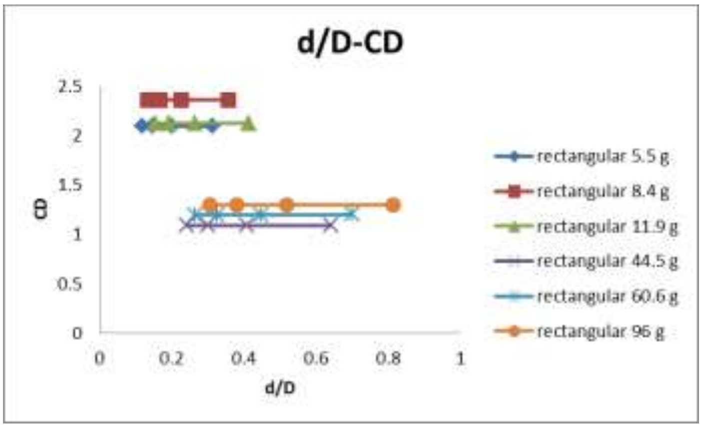


Figure (13): Relationship between (CD-d/D) for falling rectangular in water

Settling Velocity Behavior in Newtonian Fluid

For spherical particle shown the relationship between settling velocity and diameter ratio for particle to tube diameter. The velocity increasing with increasing particle diameter in the large tube (Dc=100mm) but in the smaller tube (Dc=40mm) the retarding wall effect become more pronounced therefore the velocity starts to decrease with increasing particle diameter and with increasing diameter ratio. Also this happen for all spherical and non-spherical particles figures (14) up to (18). The velocity of sphere has higher value than other particles because of the sphericity.

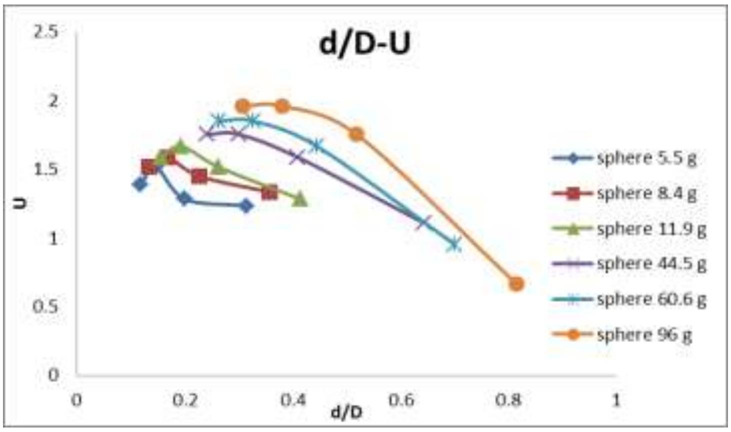


Figure (14): Relationship between (U-d/D) for falling sphere in water

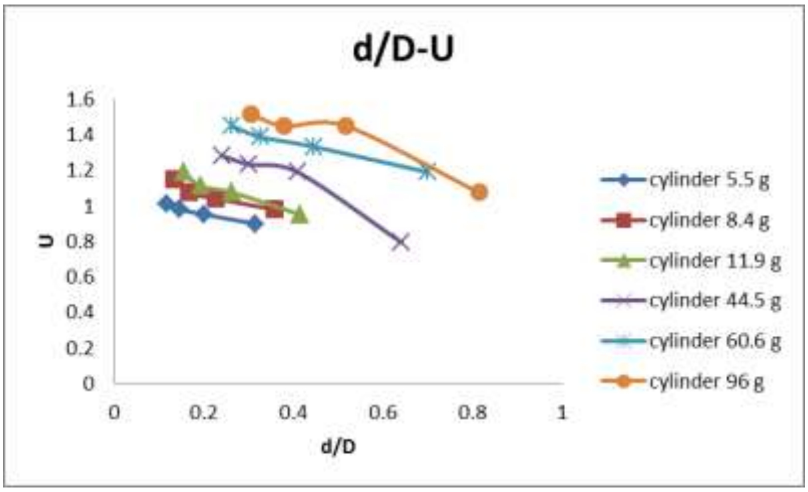


Figure (15): Relationship between (U-d/D) for falling cylinder in water

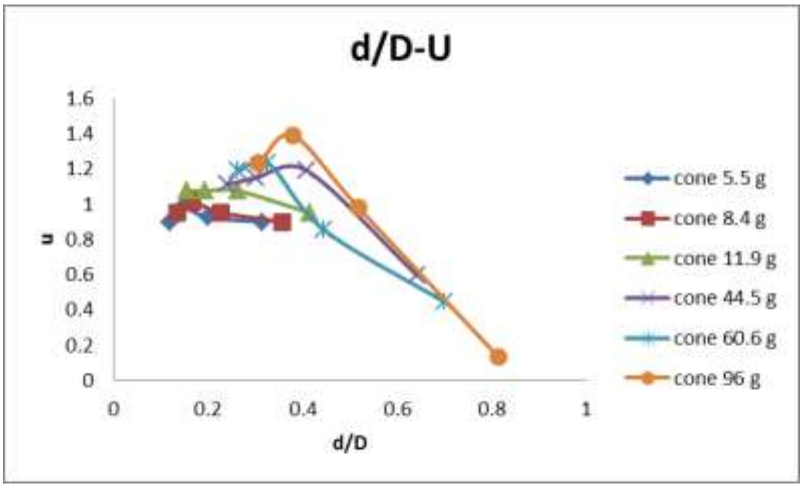


Figure (16): Relationship between (U-d/D) for falling cone in water

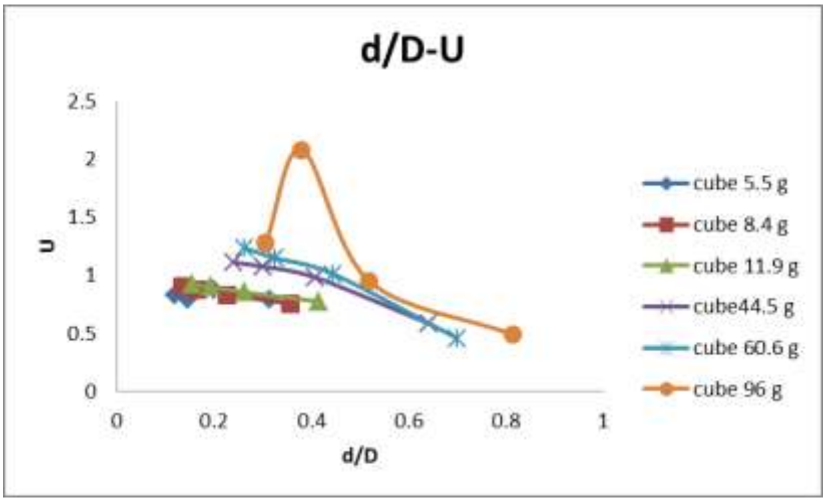


Figure (17): Relationship between (U-d/D) for falling cube in water

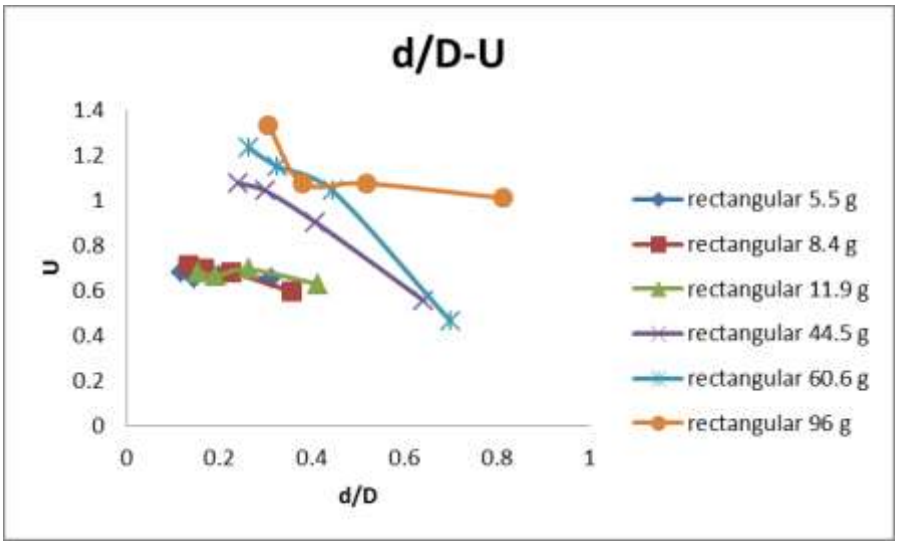


Figure (18): Relationship between (U-d/D) for falling rectangular in water

Wall Effect Behavior in Newtonian Fluid

Figures (19) up to (23) show the relationship between the wall correction factor and diameter ratio. The wall correction factor is the ratio for velocity finite fluid to velocity in an infinite fluid. The wall correction factor decreases with increasing diameter ratio, less value for wall correction factor having higher wall effect, having low Reynolds number and higher diameter ratio, it is well known that the found of the wall introduced a retarding effect on the settling velocity for particle the understand this effect is very necessary to reduce the net drag hydrodynamic on the particles. Also the wall effect increase with increasing the diameter ratio because the finite wall will produce an extra retardation force on the particle falling in fluid. This is because of fluid flux up ward displaced by particle through the gap between the container wall and surface particle. When the gap be narrower the retardation force increase and this lead to reduce the velocity field around the particle the drag force increase and then the settling velocity decrease this behavior for same particle in all tube.

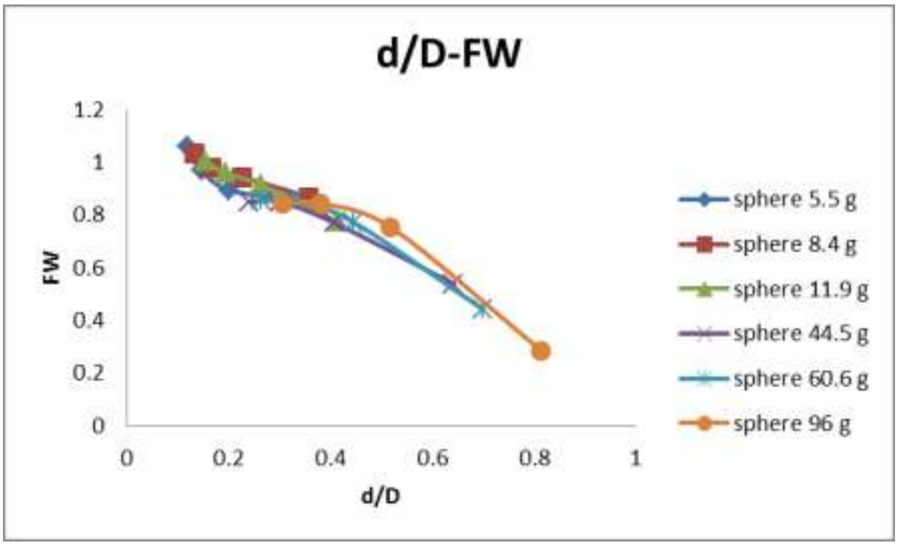


Figure (19): Relationship between (FW-d/D) for falling sphere in water

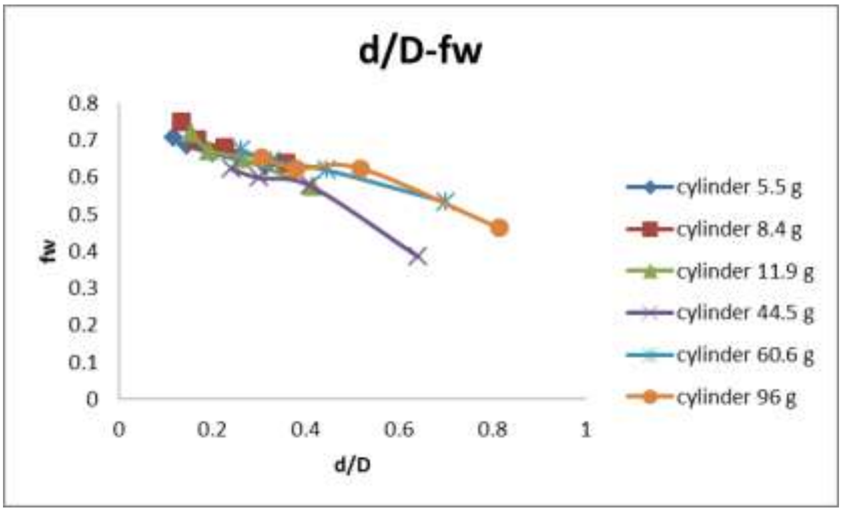


Figure (20): Relationship between (FW-d/D) for falling cylinder in water

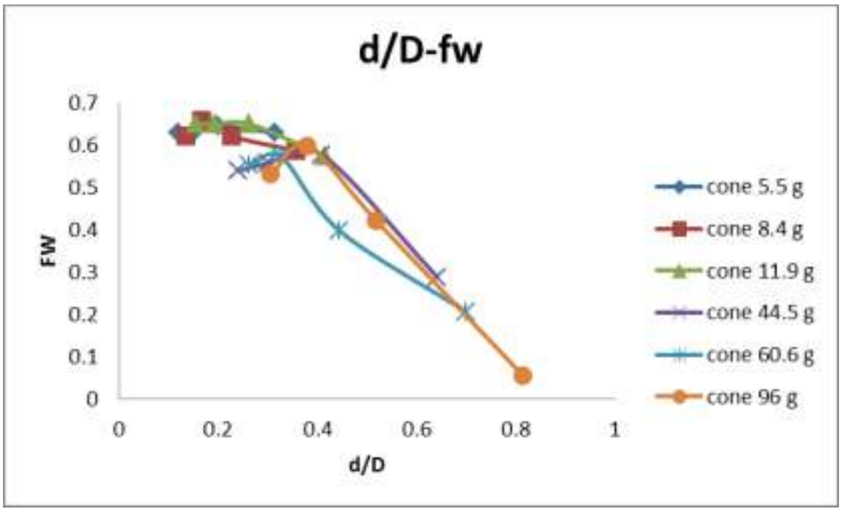


Figure (21): Relationship between (FW-d/D) for falling cone in water

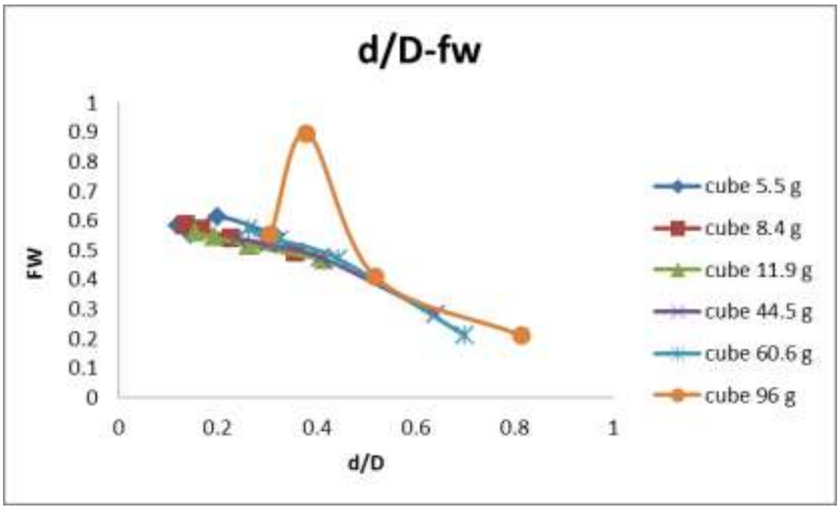


Figure (22): Relationship between (FW-d/D) for falling cube in water

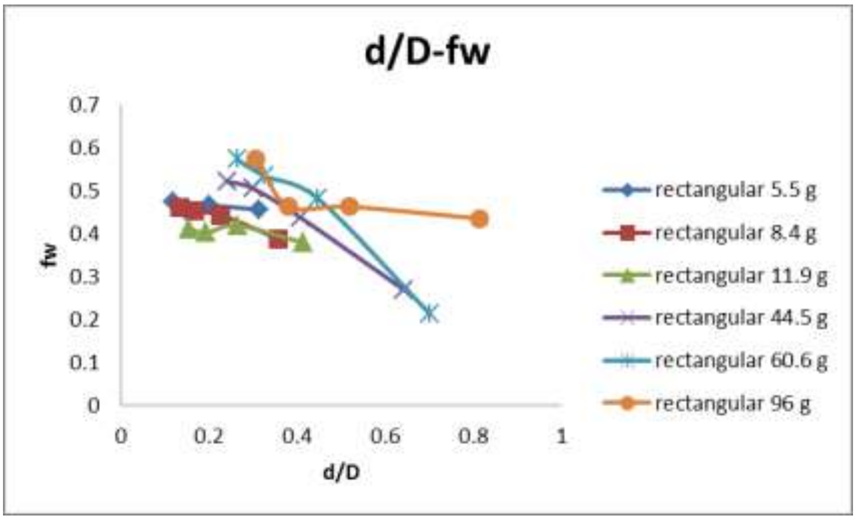
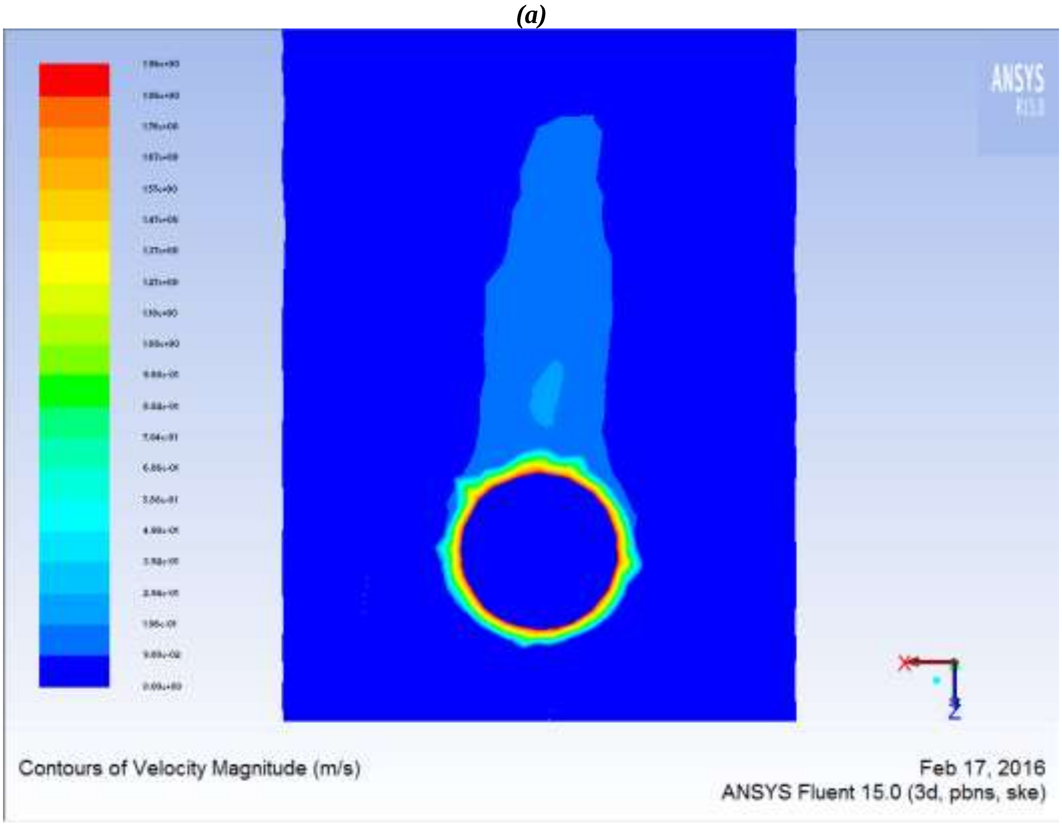


Figure (23): Relationship between (FW-d/D) for falling rectangular in water

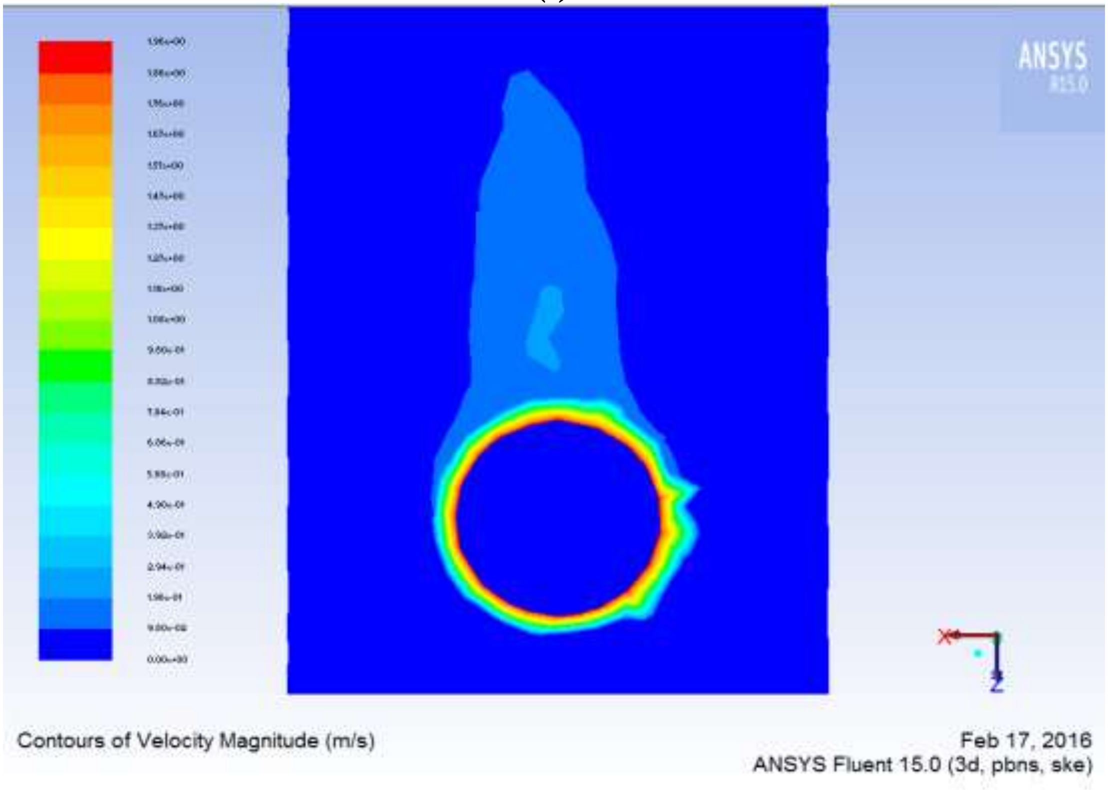
Wake Characteristics Behavior

From figures (24)up to(28) show the simulation for experimental data by using ANSYS FLUENT 15 for particles having weight 96g falling in the four tubes .This simulation given insight for the velocity profile contours for the flow the effect of finite wall on the particle surface in fluid are subjected to higher shearing .The wake characteristics described by recirculation length that measure from the rear of the particle at low Reynolds number the flow remains attached to the particle surface when Reynolds number turbulent the flow will separate near the rear region .Also in Newtonian fluid the wake region is smaller because the separation delayed and the flow for boundary layer turbulent.

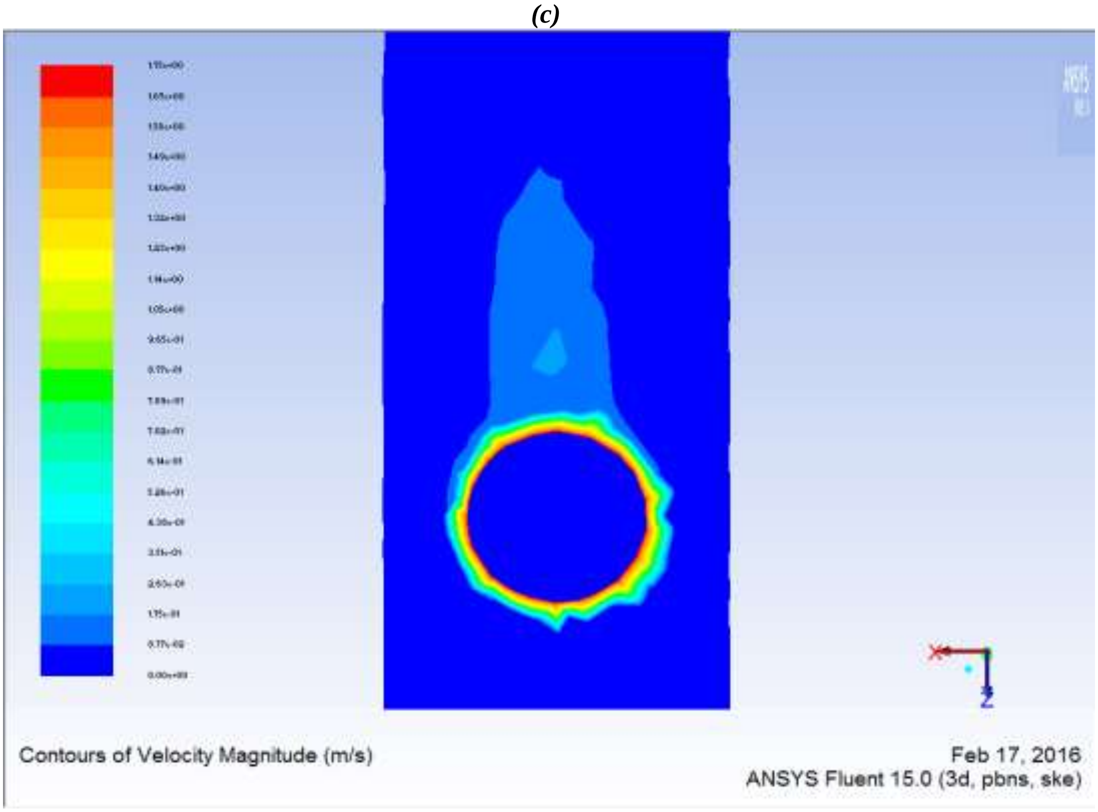
(a)



(b)


ANSYS
R15.0
Contours of Velocity Magnitude (m/s)
Feb 17, 2016
ANSYS Fluent 15.0 (3d, pbns, ske)

(c)


Contours of Velocity Magnitude (m/s)
Feb 17, 2016
ANSYS Fluent 15.0 (3d, pbns, ske)

(d)

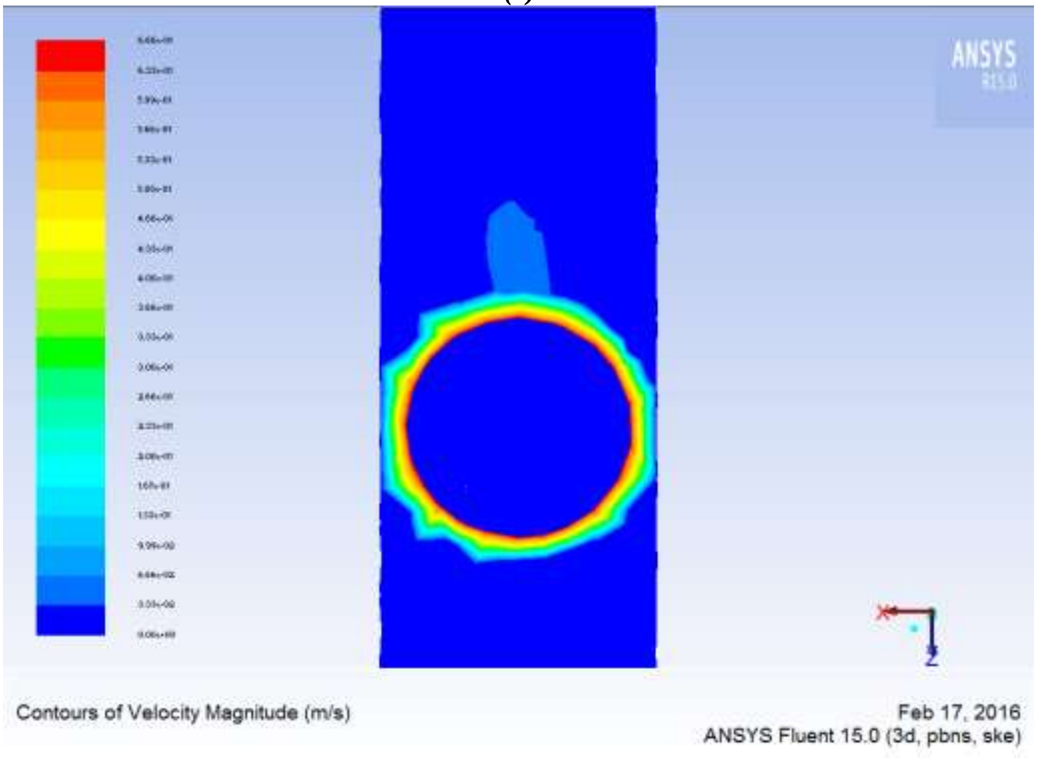
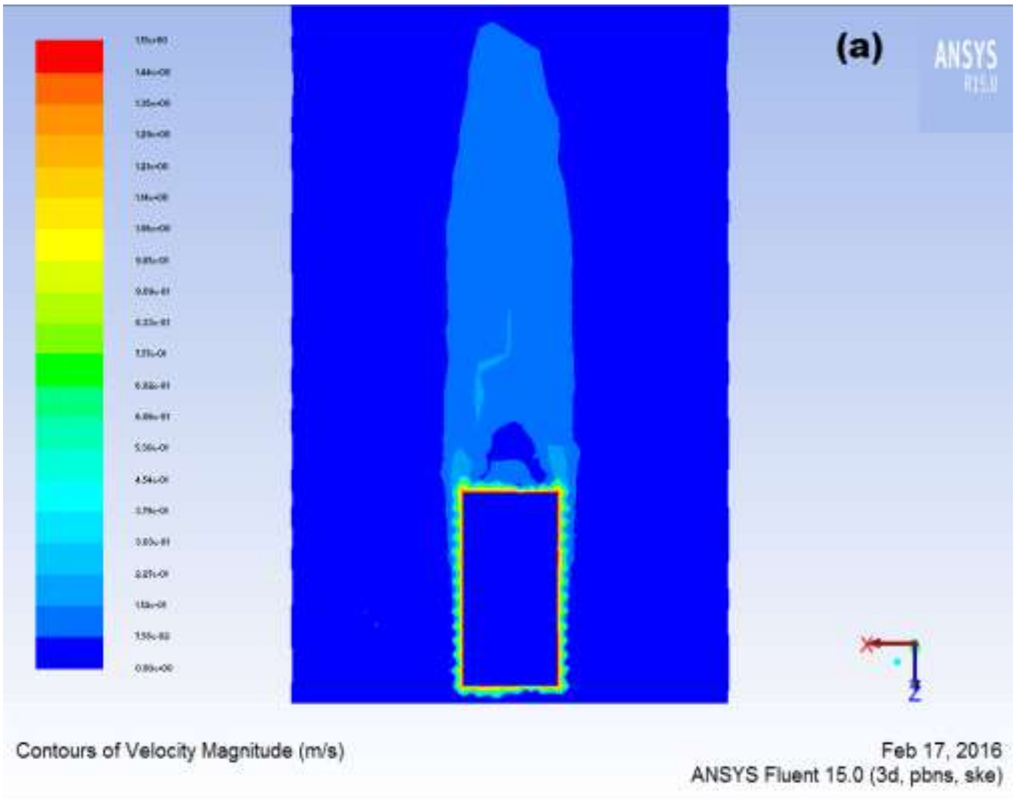


Figure (24): sphere (96 g) falling in four tube in water (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm



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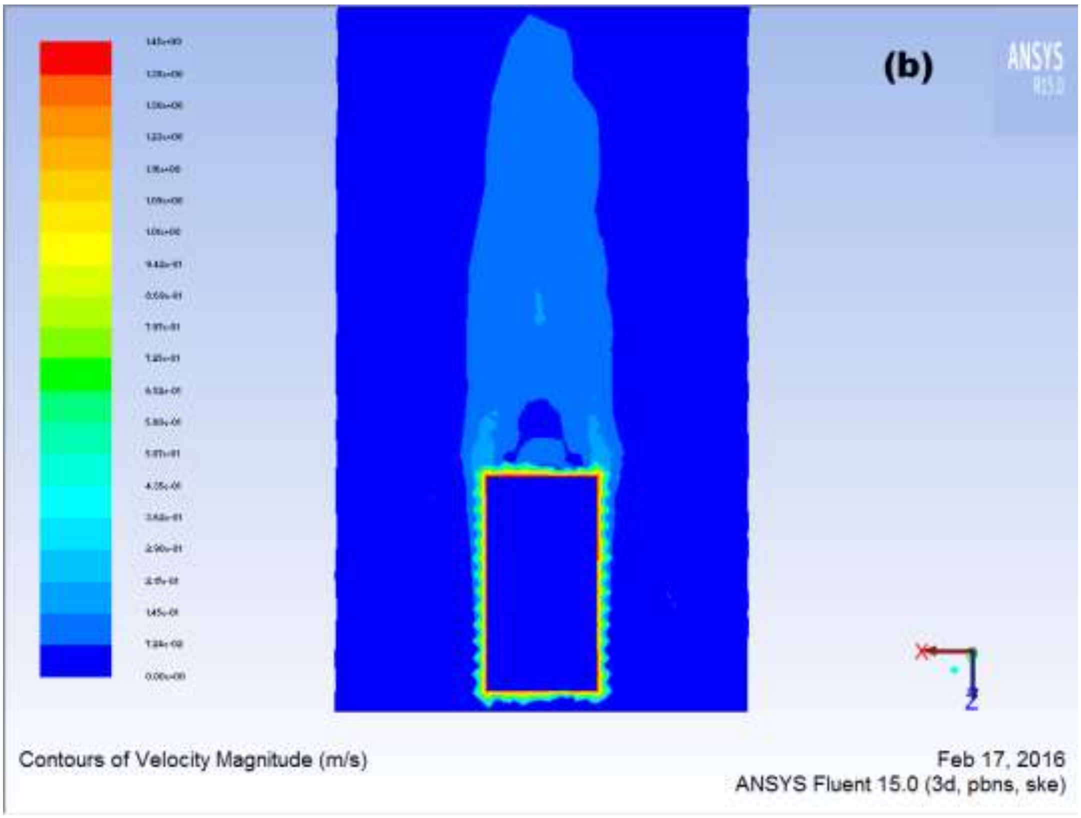
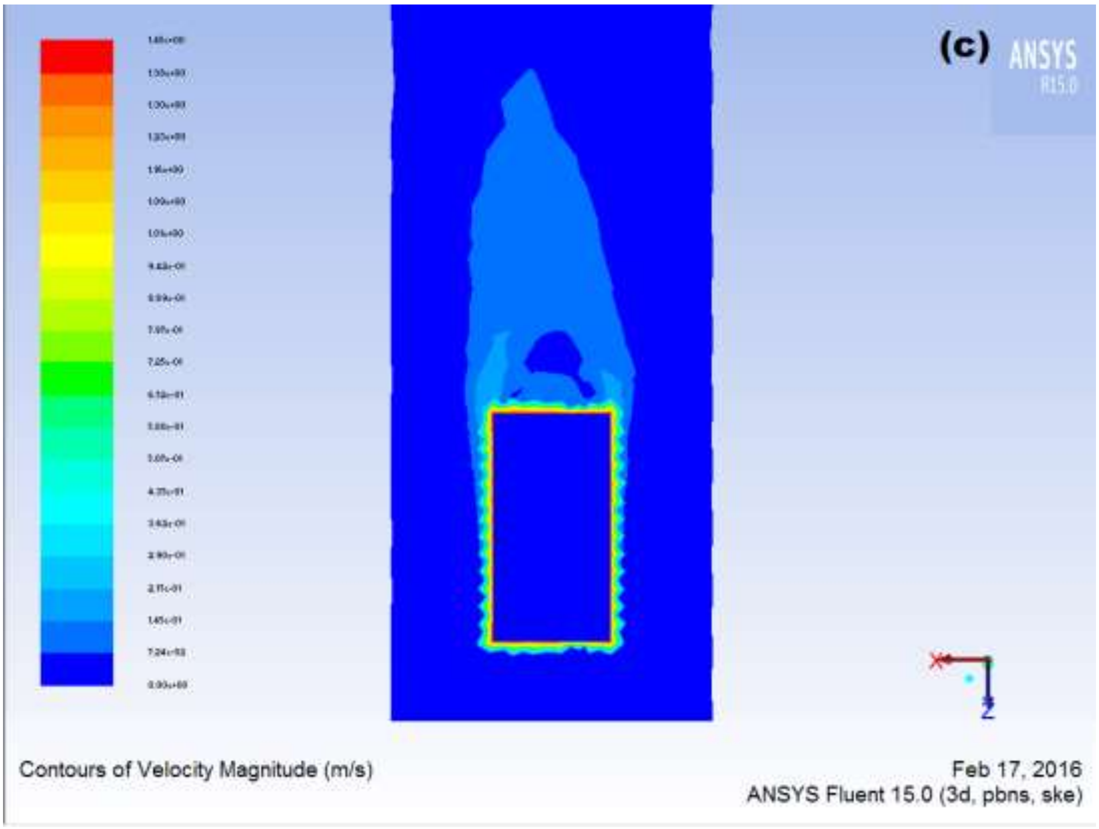




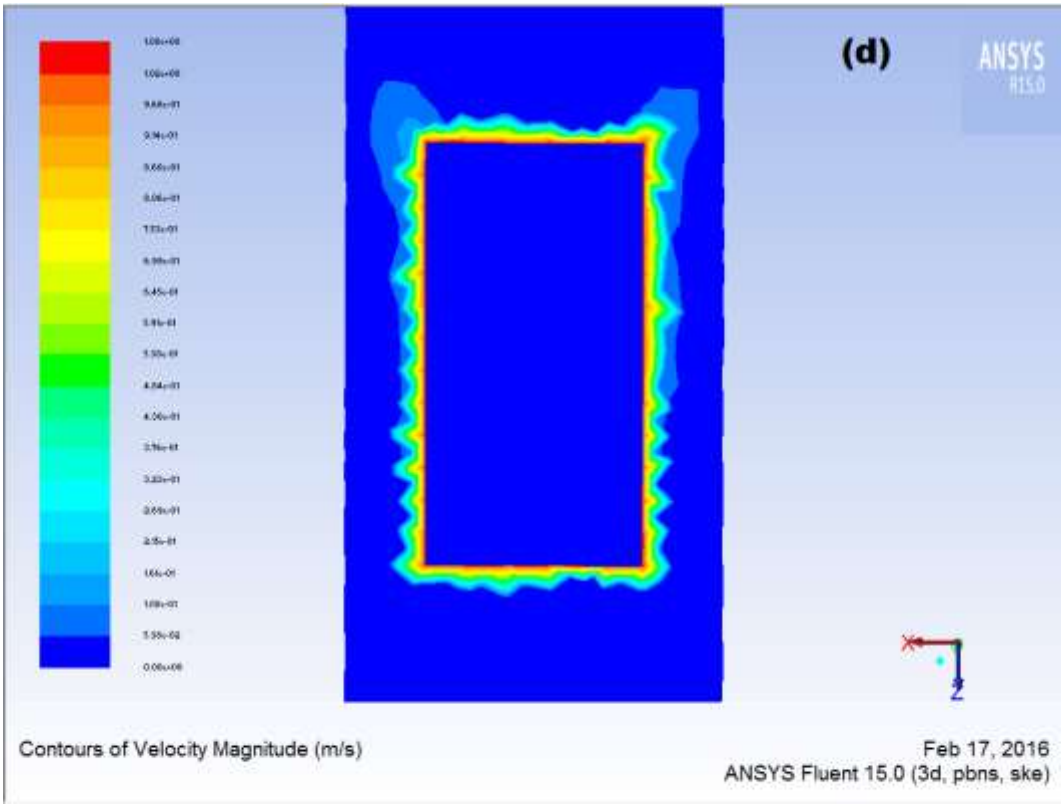
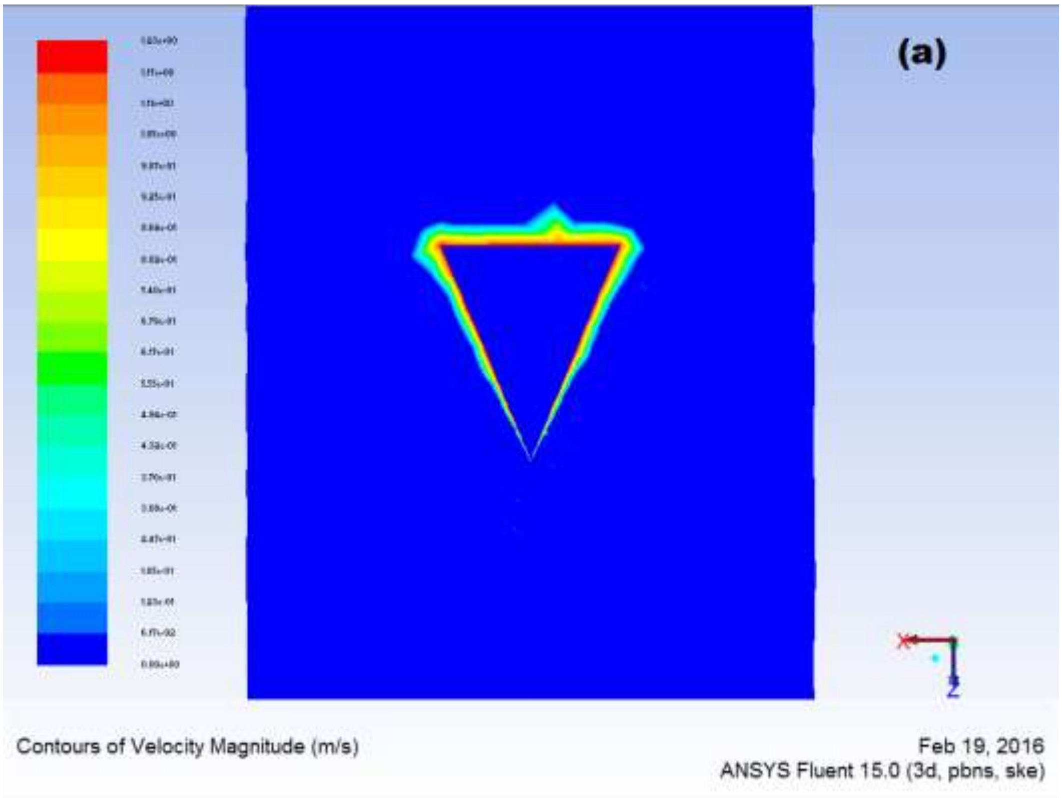
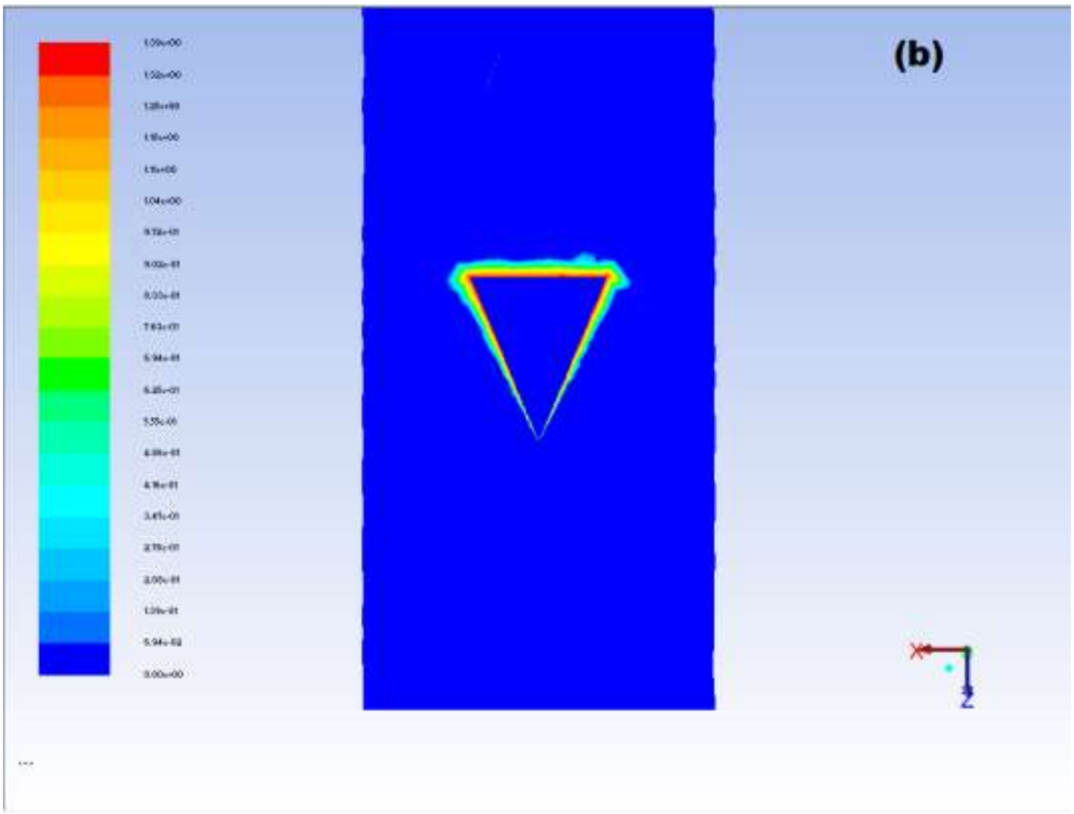


Figure (25): cylinder 96gfalling in water in four tube (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

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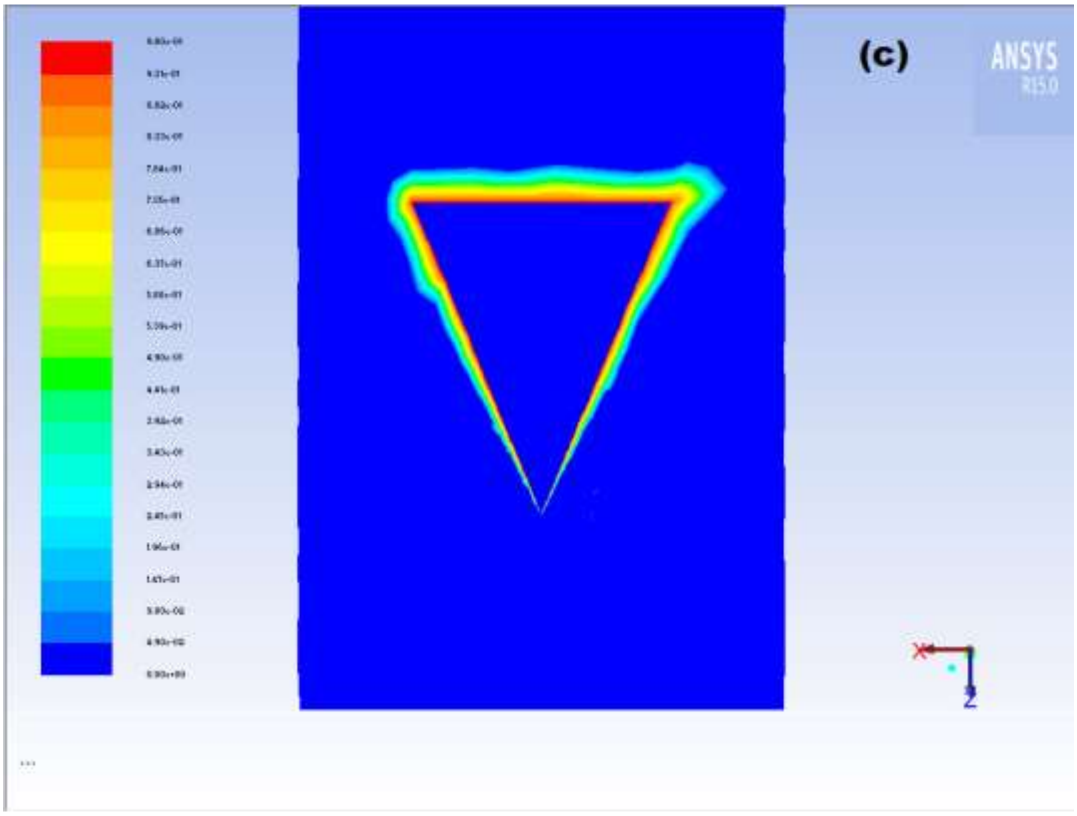
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ANSYS

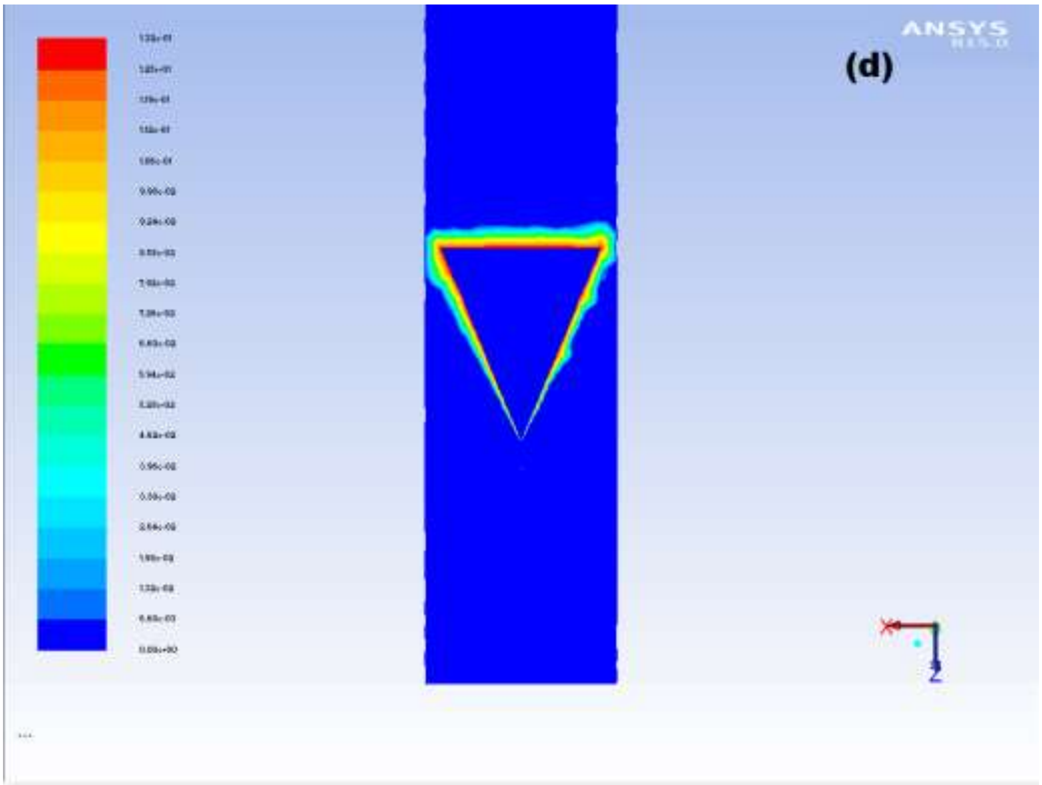
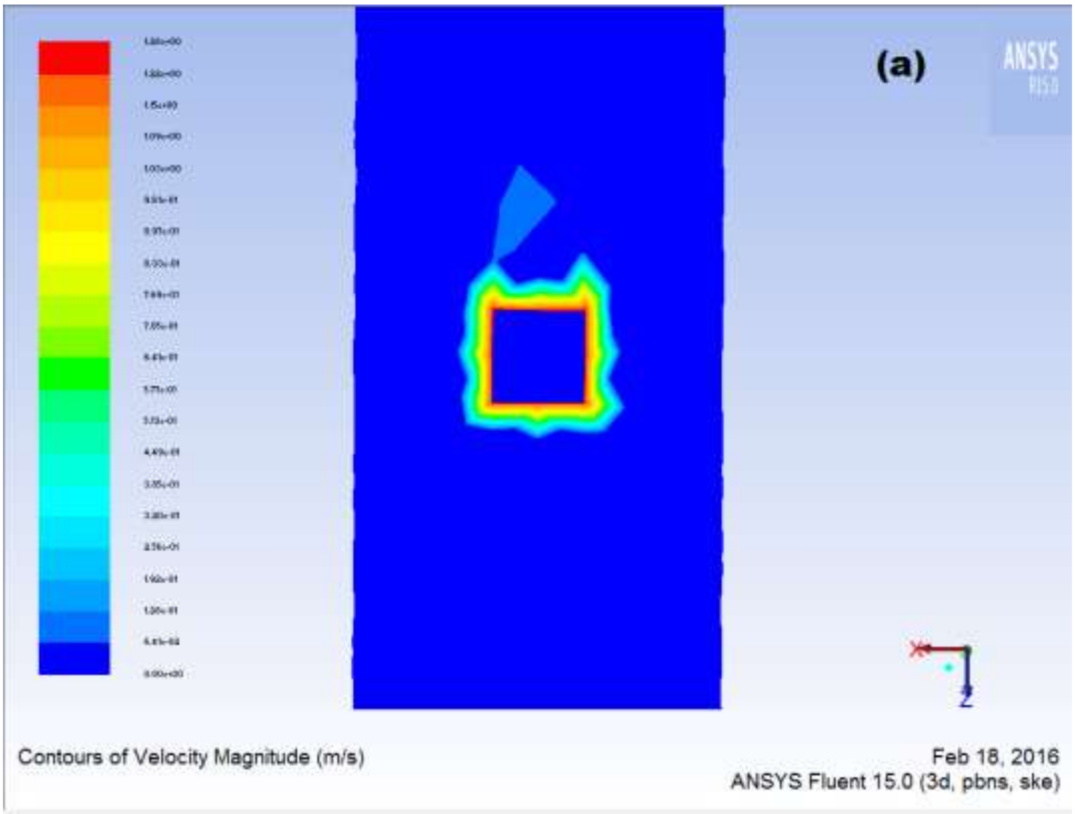
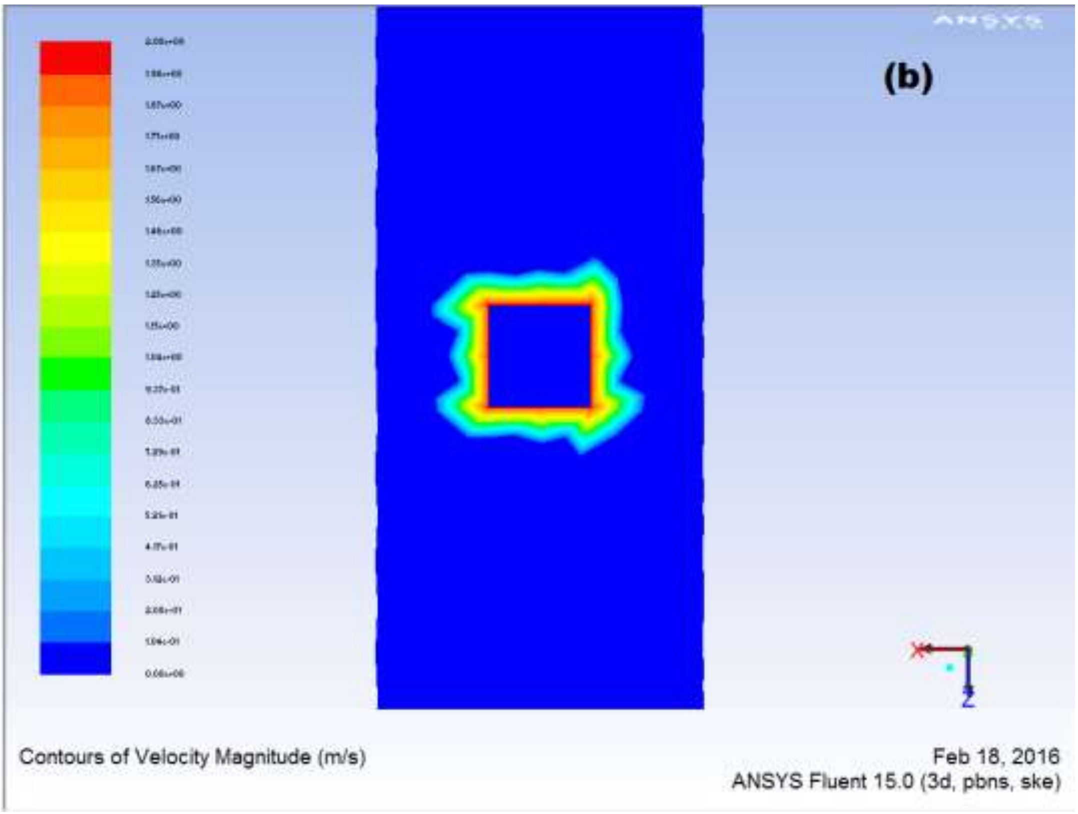


Figure (26) cone falling 96 g in four tube in water (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

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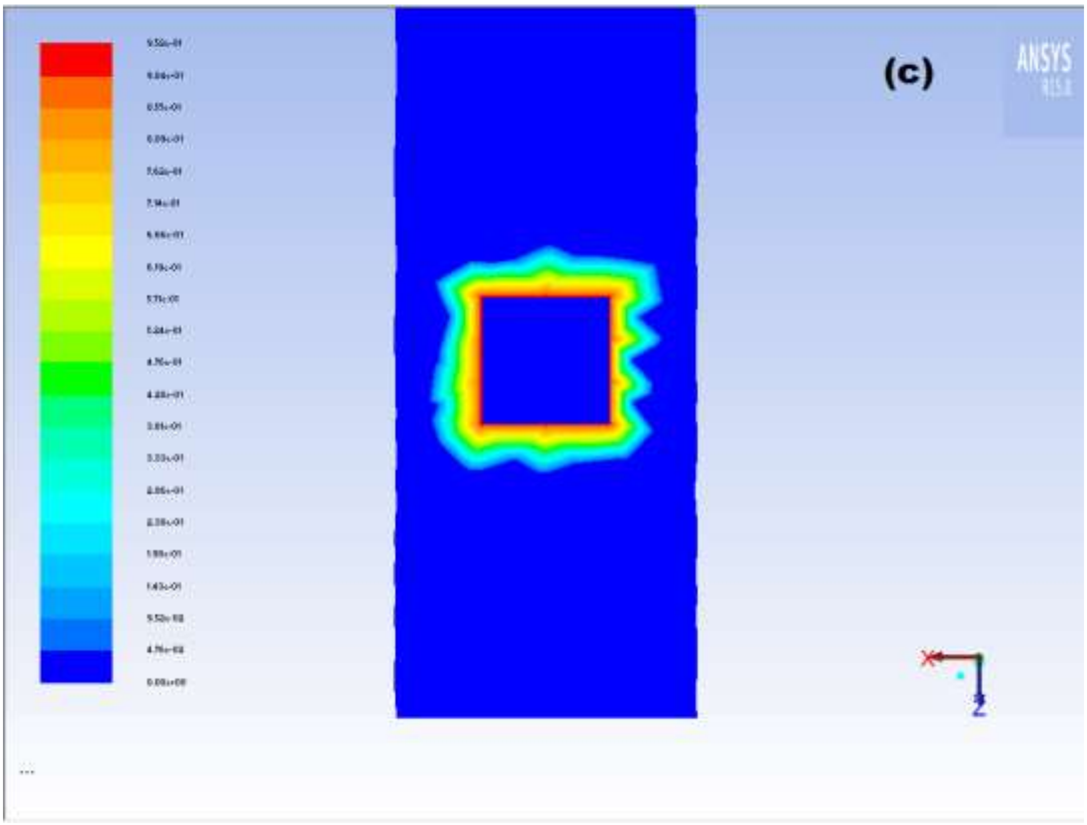
Contours of Velocity Magnitude (m/s)
Feb 18, 2016
ANSYS Fluent 15.0 (3d, pbns, ske)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ANSYS

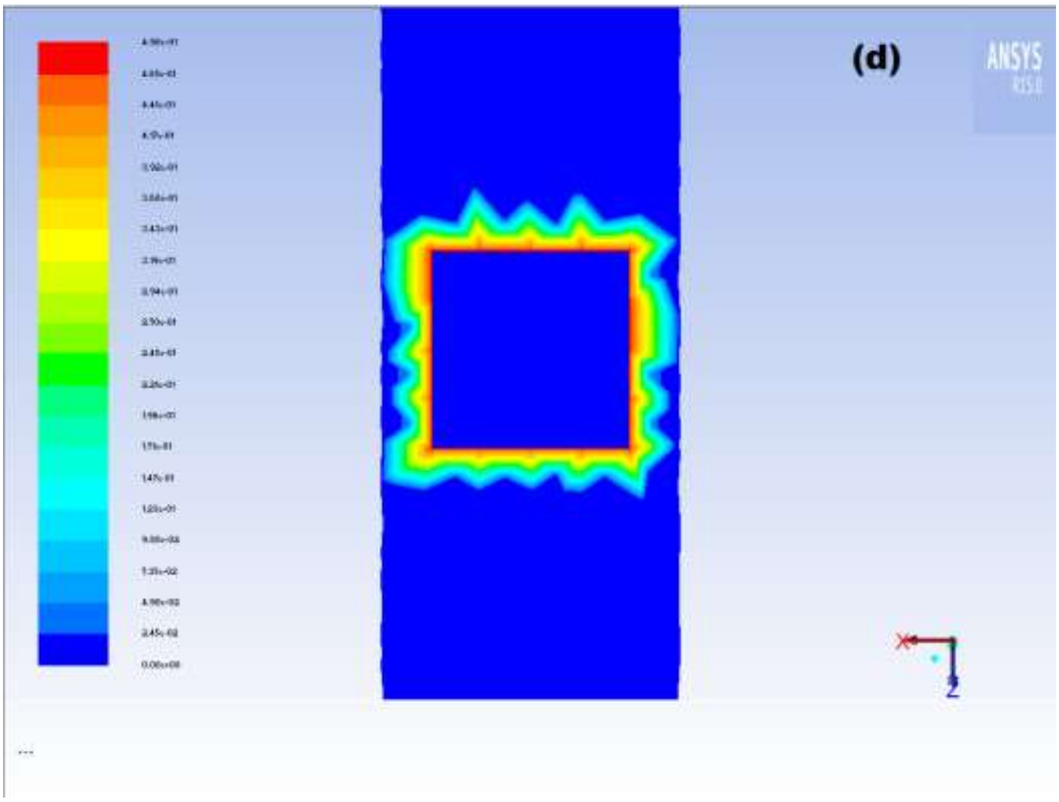
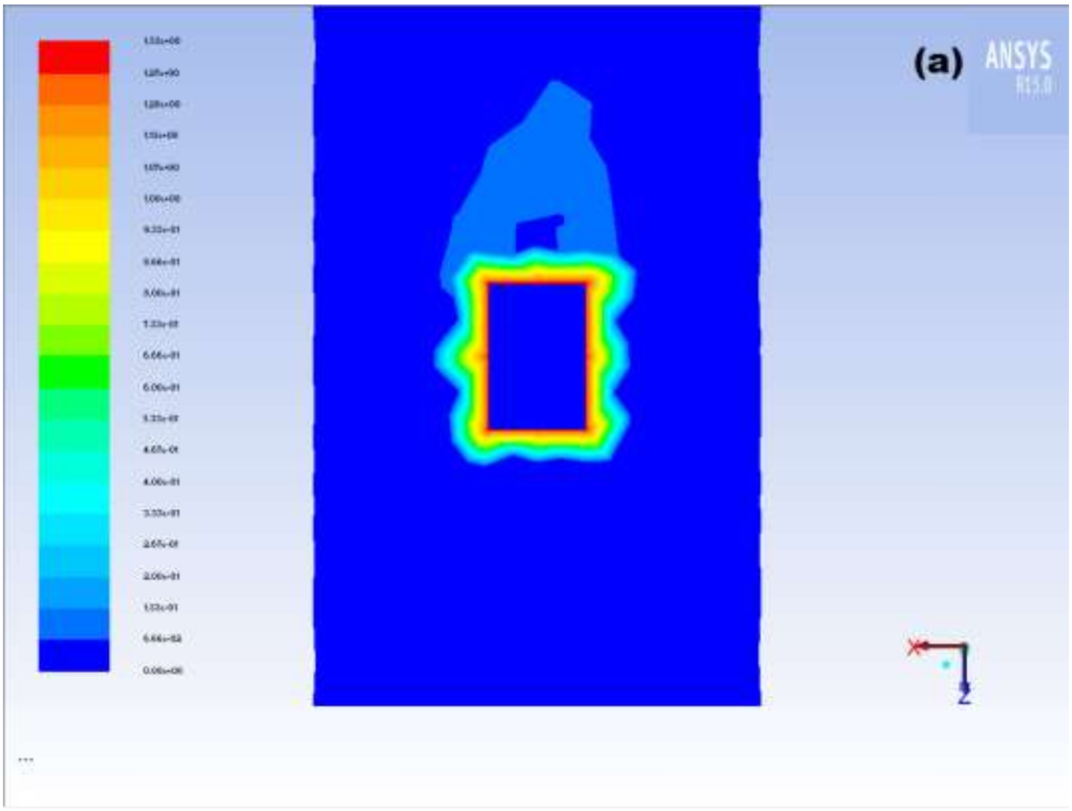
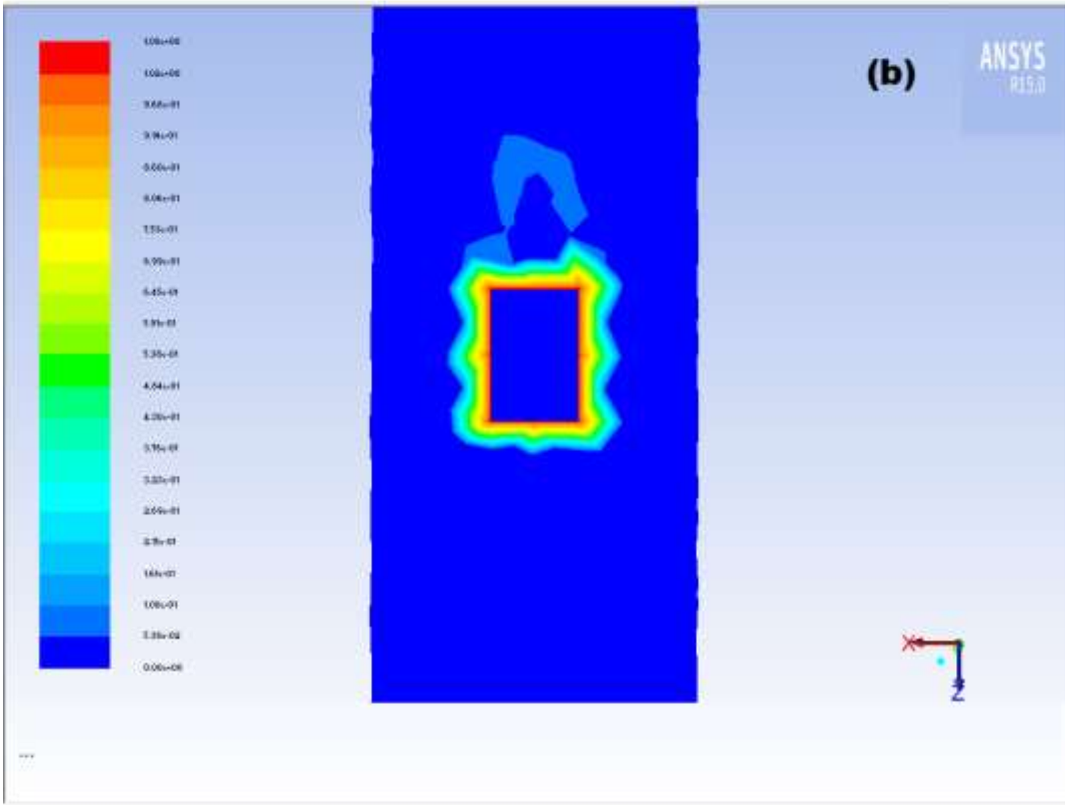


Figure (27) cube 96g falling in four tube in water (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm




(b)
ANSYS
R15.0
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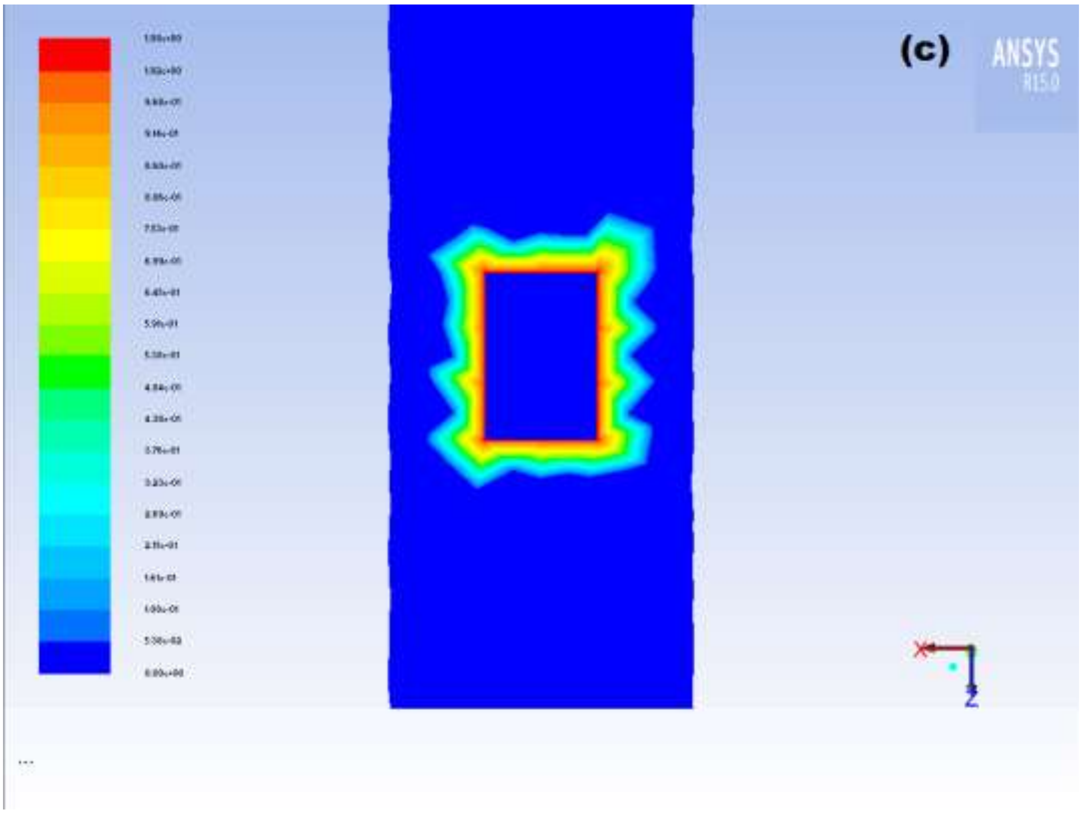
Z


(c)
ANSYS
R15.0
X
Z

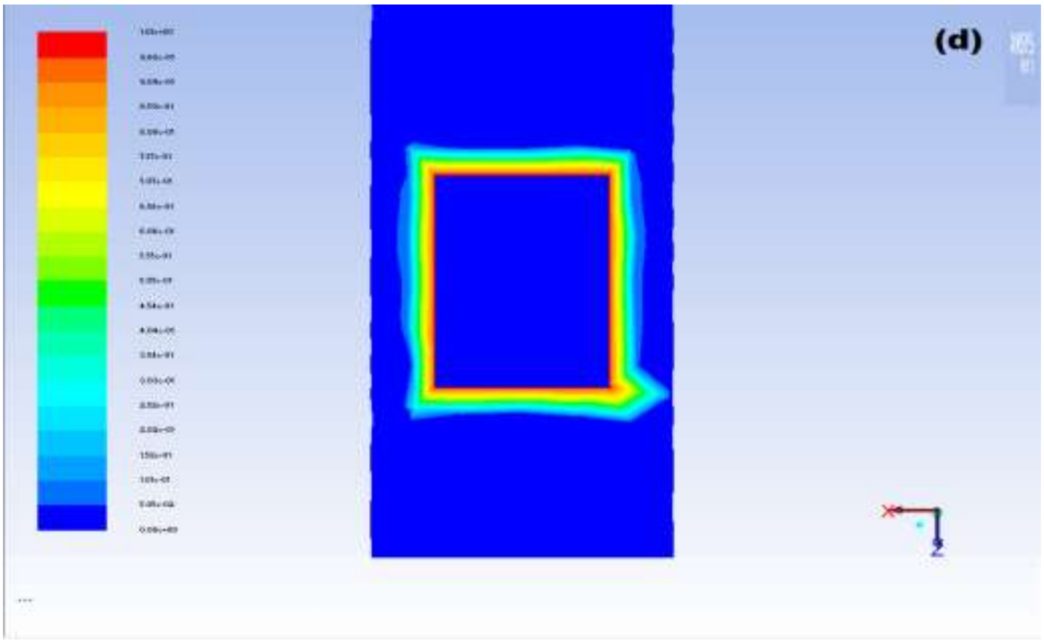


Figure (28): rectangular 96g falling in four tube in water (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

Non-Newtonian Fluid

Drag Coefficient Behavior in Non –Newtonian Fluid

For Spherical particle figure (29) the plotting between (Re-CD)shown that the drag coefficient decrease with increasing in Reynolds number and the result shown the flow around the particle is laminar so when the laminar slip region started the drag coefficient decrease because that the viscous force are dominate in this region and the flow behavior index less than one . For non –spherical particle figures (30) up to (33). From results the relationship between (Re-CD) for all non-spherical particle shown the drag coefficient decreases with increasing Reynolds number. The drag coefficient for rectangular are greater than the other particles because the drag coefficient depend on the sphericity. When sphericity has minimum value the maximum drag coefficient happen for example rectangular (5.5 g)weight having (0.69) sphericity having maximum .value for drag coefficient .Also the drag coefficient not depended on the weight of particle because rectangular (11.9g)with sphericity (0.68)having drag coefficient greater than that for cylinder ,cube ,cone with sphericity (0.87 , 0.711,0.74) respectively and weight (5.5 g) as shown in figures (34) up to(37).

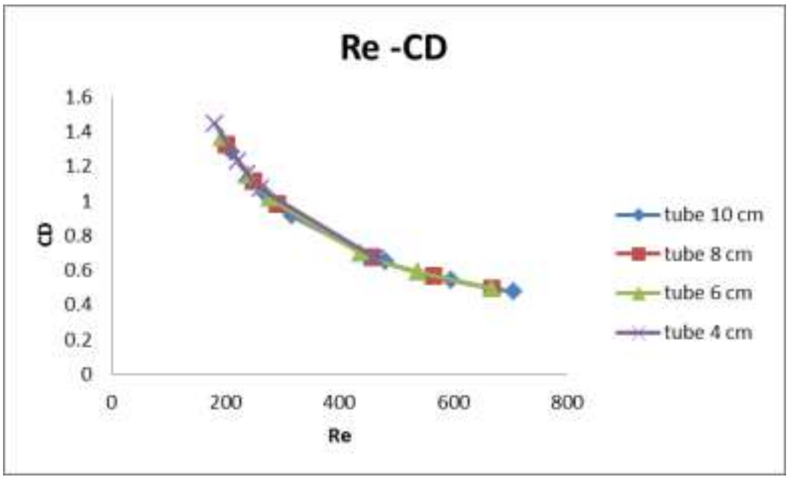


Figure (29): Relationship of (CD-Re) for falling sphere in CMC

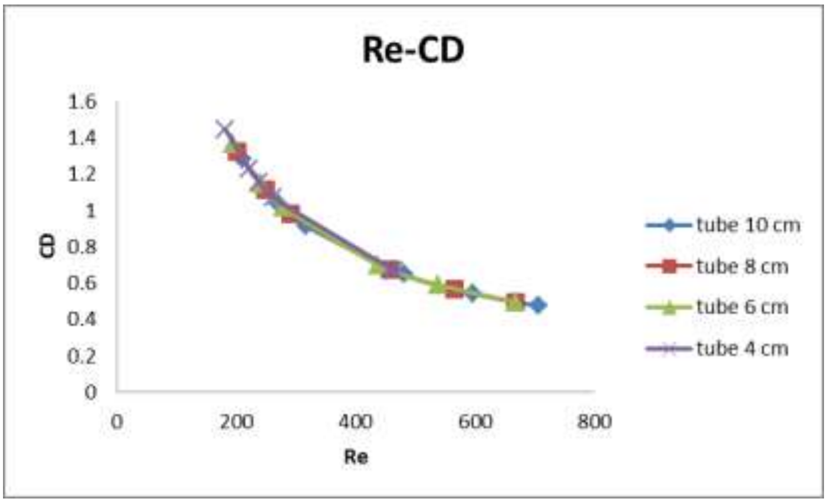


Figure (30): Relationship of (CD-Re) for falling cylinder in CMC

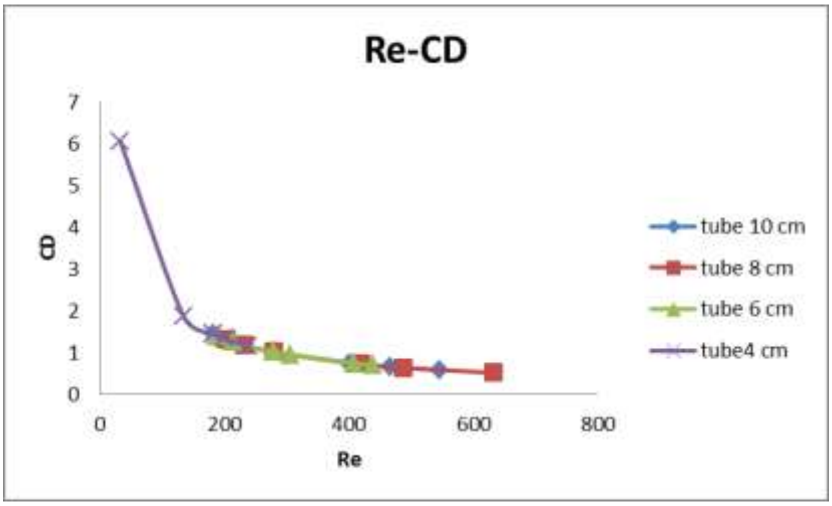


Figure (31): Relationship of (CD-Re) for falling cone in CMC

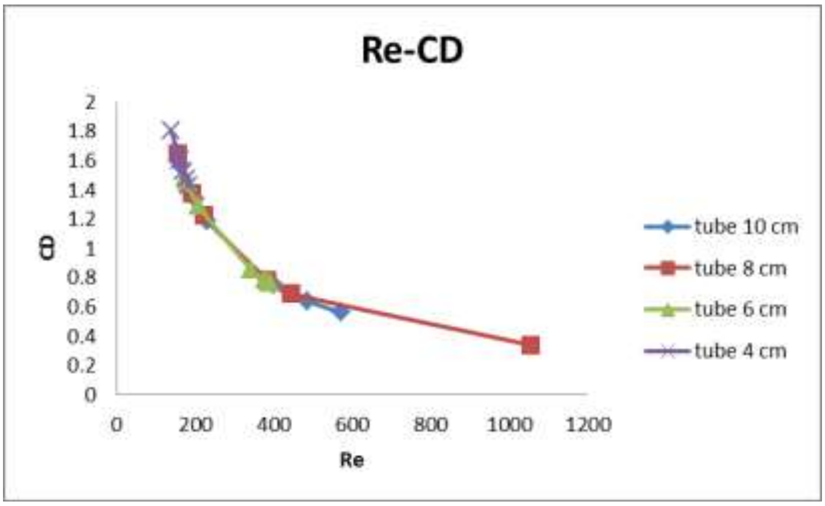


Figure (32): Relationship of (CD-Re) for falling cube in CMC

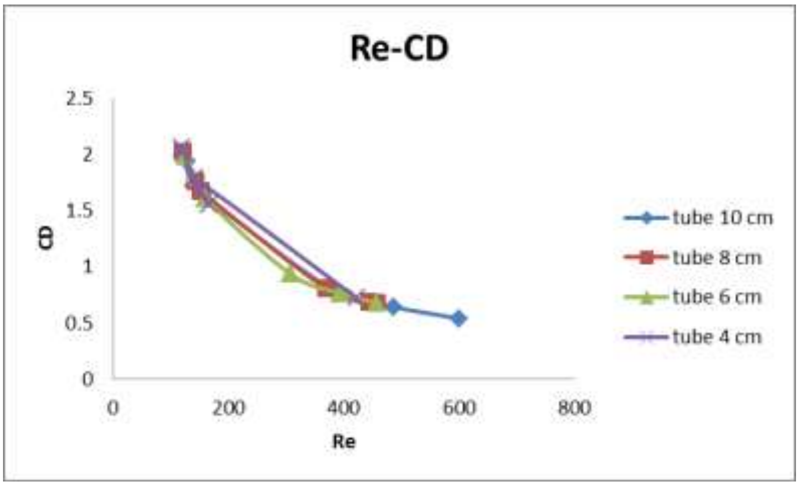


Figure (33): Relationship of (CD-Re) for falling rectangular in CMC

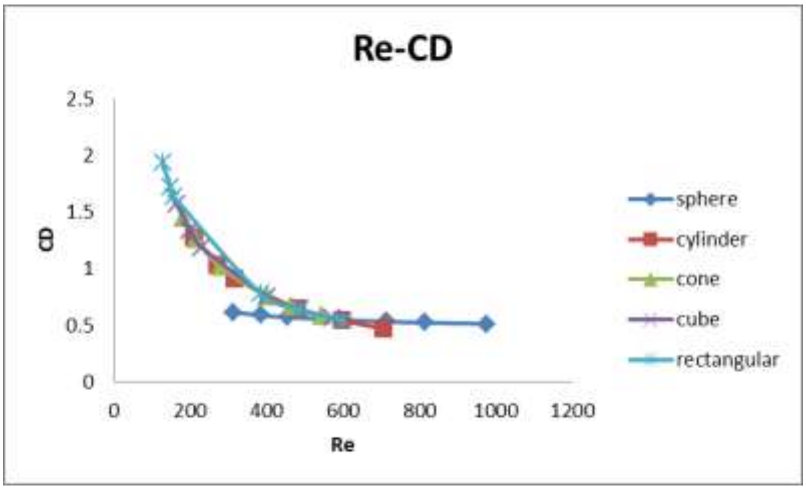


Figure (34): Comparison of relationship between (CD-Re) for falling in tube 10 cm spherical and non-spherical particle in CMC

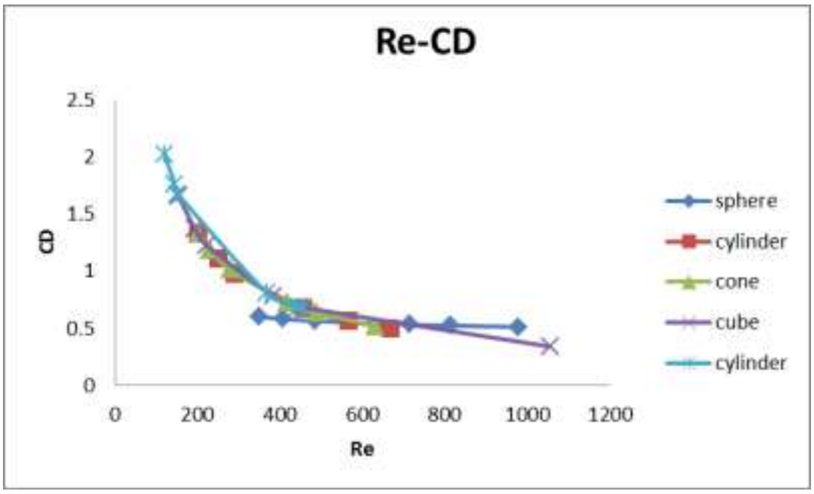


Figure (35): Comparison of relationship between (CD-Re) for falling in tube 8 cm spherical and non-spherical particle in CMC

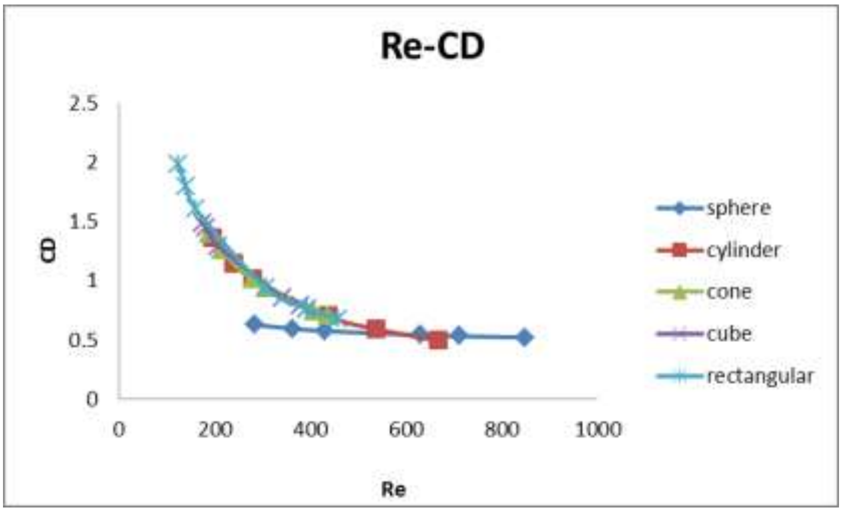


Figure (36): Comparison of relationship between (CD-Re) for falling in tube 6 cm spherical and non-spherical particle in CMC

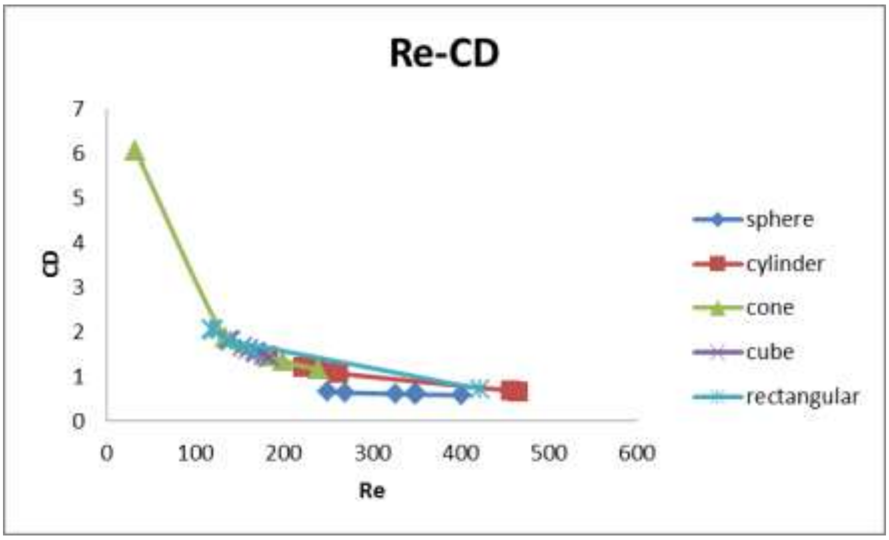


Figure (37): Comparison of relationship between (CD-Re) for falling in tube 4 cm spherical and non-spherical particle in CMC

The effect for container diameter on drag coefficient in non –Newtonian fluid

Figures (38) up to (42) show the relationship between diameter ratios and drag coefficient for the same particle settling in the four tubes. When the diameter ratio increase lead to increase in drag coefficient because the effect of finite boundaries lead to an increase in the drag force. When the particle settling in fluid it displaced fluid equal to the volume of particle ,the displaced fluid passing through the gap between the wall of the container and the particle surface leaving the velocity field around the particle become steeper when the diameter ratio increase, this leads to increase in drag force and then increase in drag coefficient . Also this shape for behavior is due to that the particle settling in laminar this type for flow caused the viscous force will have high effect and this force is proportional to the velocity this mean any increases in velocity or decreases effected on drag coefficient because Reynolds number dependent in this case .

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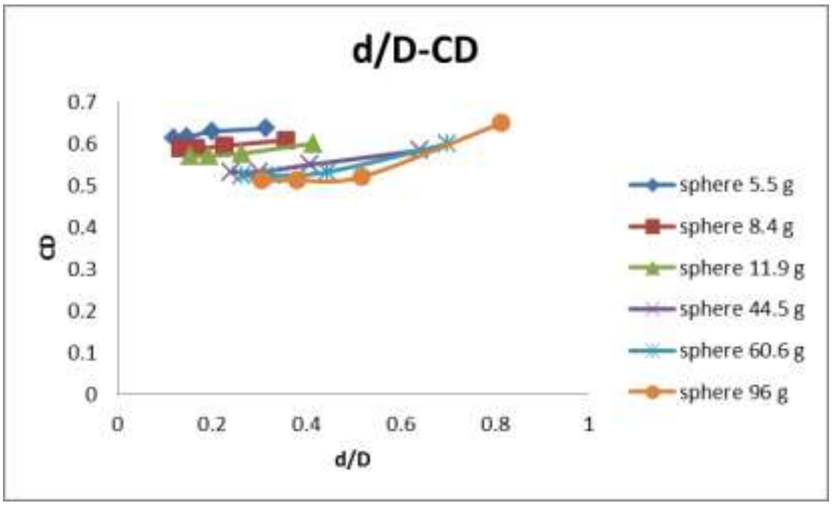

Figure (38): Relationship between (CD-d/D) for falling sphere CMC

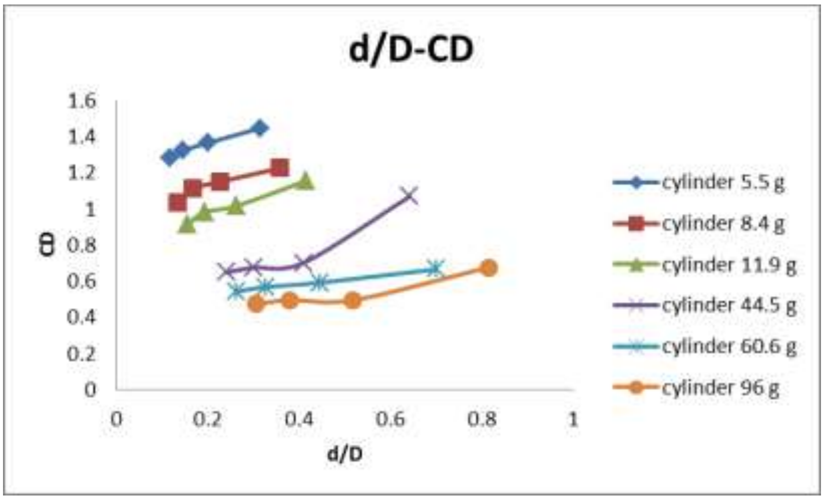

Figure (39): Relationship between (CD-d/D) for falling cylinder CMC

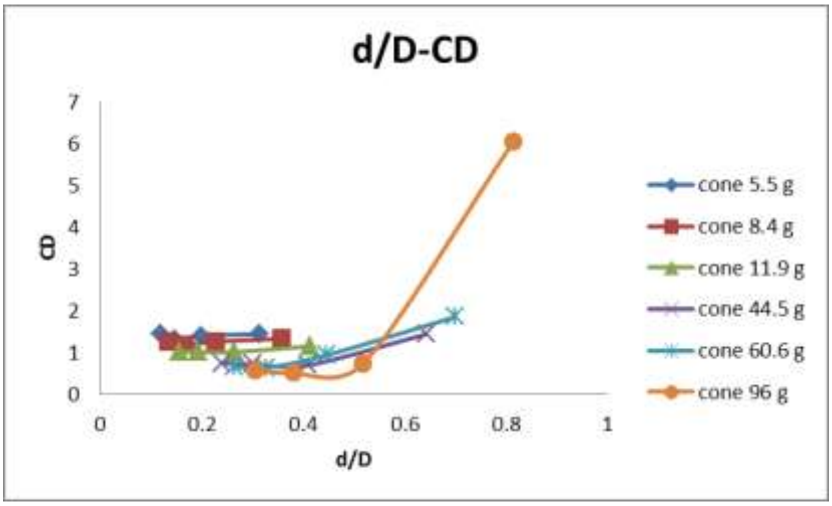

Figure (40): Relationship between (CD-d/D) for falling cone CMC

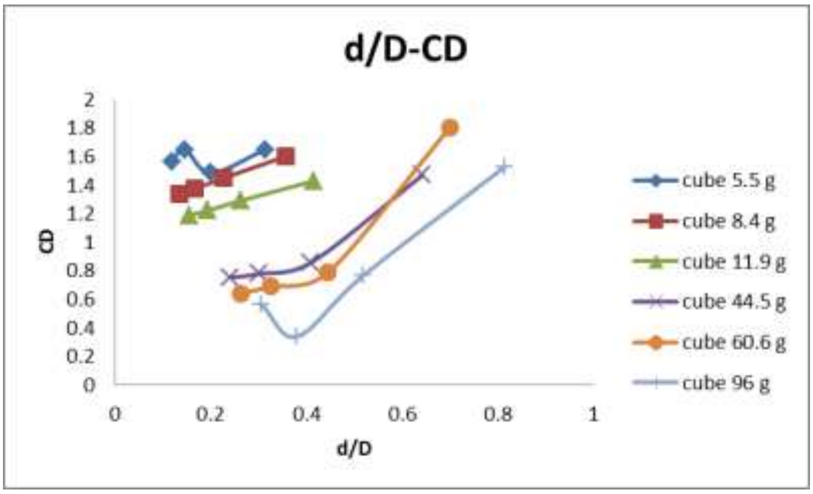

Figure (41): Relationship between (CD-d/D) for falling cube in CMC

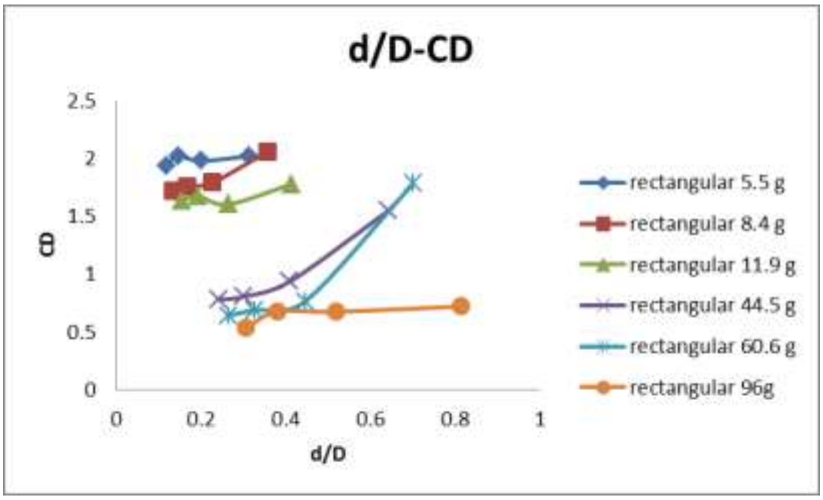

Figure (42): Relationship between (CD-d/D) for falling rectangular in CMC

Behavior for Settling Velocity in Non –Newtonian Fluid

From figures (43)up to(46) it show the same behavior for Newtonian fluid but the value for settling velocity is greater than Newtonian fluid, the value of increment for the sphere ,cylinder ,cone ,cube , rectangular (3.21,13.02,14.8,9.94,3.8) respectively , this return to the wall effect on particle when the particle subjected to high wall effect the value in non- Newtonian less than Newtonian fluid because in this work used non- Newtonian fluid having flow index (n<1)this lead that fluid as shear thinning fluid in this type of fluid the viscosity decreases with increasing shear stress this mean that the viscosity is dependent on the forces exerted in the fluid but in Newtonian fluid the viscosity independent on forces exerted in the fluid .Thus for this reason lubricating engine parts and also the smaller in power law index lead to smaller in the wall effect Daoyun Song (2011) .

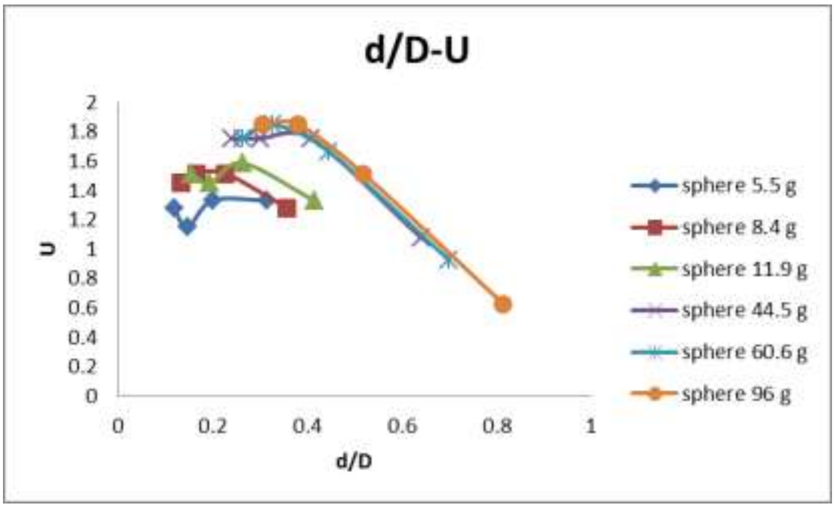

Figure (43): Relationship between (U-d/D) for falling sphere in CMC

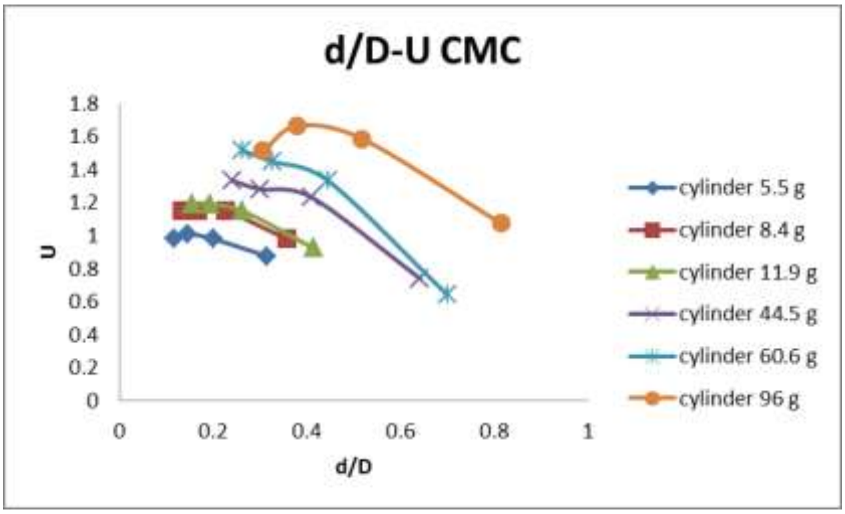

Figure (44): Relationship between (U-d/D) for falling cylinder in CMC

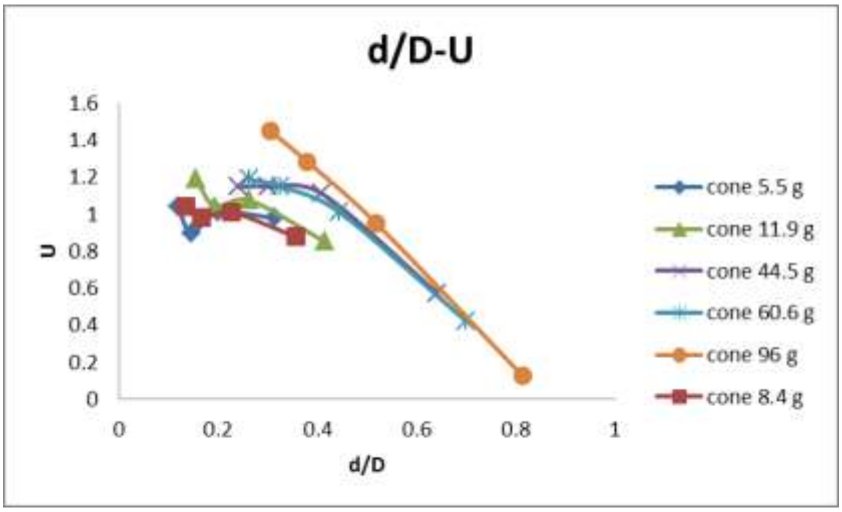

Figure (45): Relationship between (U-d/D) for falling cone in CMC

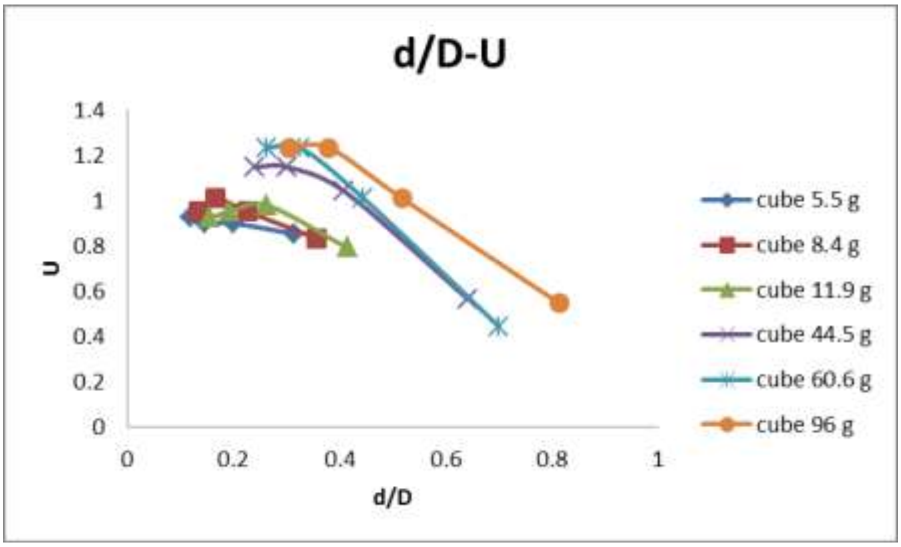

Figure (46): Relationship between (U-d/D) for falling cube in CMC

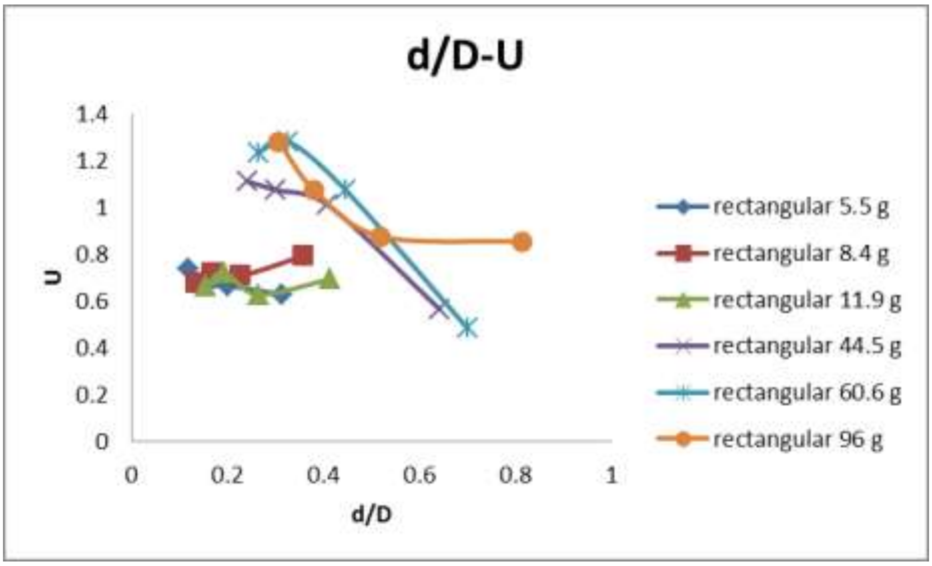

Figure (47): Relationship between (U-d/D) for falling cube in CMC

Wall Effect Behavior in Non- Newtonian Fluid

From figures (48) up to(52) show the relationship between wall correction factor and diameter ratio similarly to the behavior in Newtonian fluid but the wall effect is less in non- Newtonian fluid than Newtonian because the behavior for non- Newtonian fluid as shear thinning ($n<1$)while in Newtonian fluid ($n=1$). When flow behavior index decreases the effective viscosity decreases then lead to increases shear stress thus when viscosity decrease lead to reduce retarding force than Newtonian fluid So, from all the above the wall effect depend on diameter ratio, Reynolds number , shape ,and type of fluid. In the case of non- spherical particles, the wall correction factor with diameter ratio is the same behavior for spherical particles because the equivalent diameter equal to the diameter for sphere.

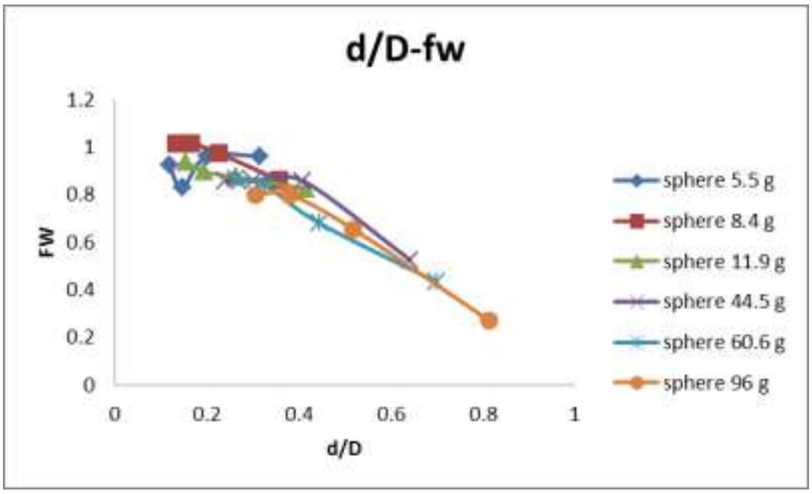

Figure (48): Relationship between (FW-d/D) for falling sphere in CMC

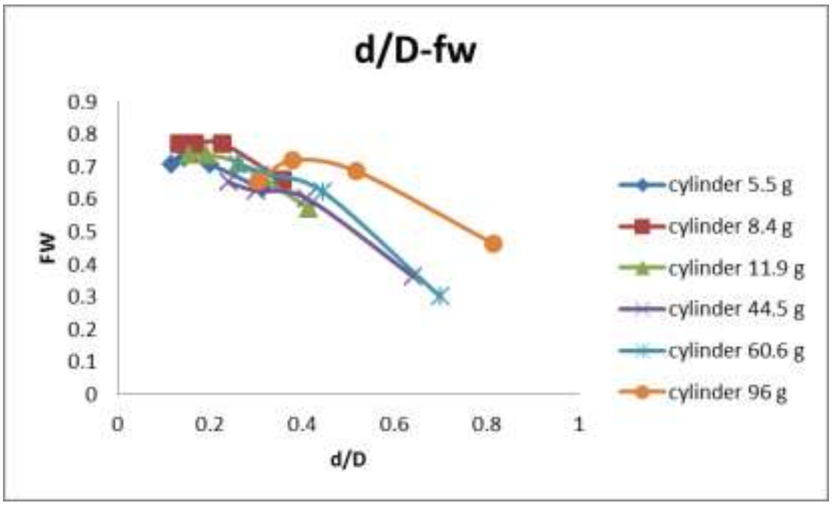

Figure (49): Relationship between (FW-d/D) for falling cylinder in CMC

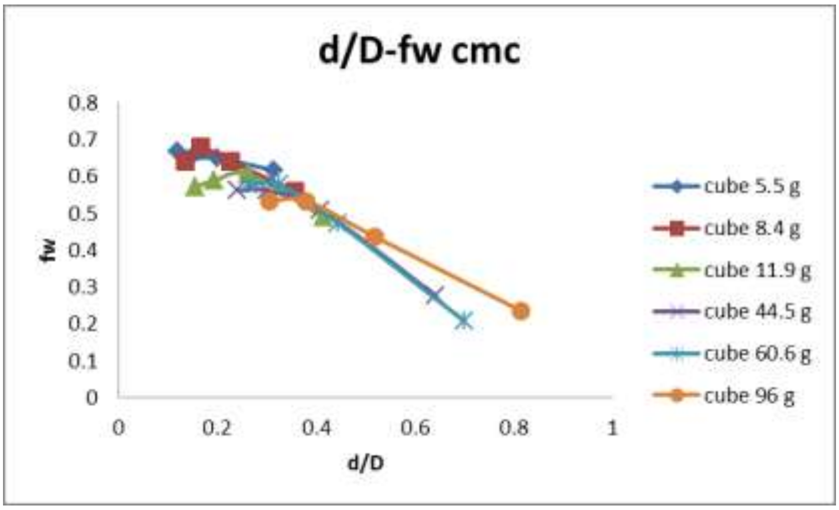

Figure (50): Relationship between (FW-d/D) for falling cube in cmc

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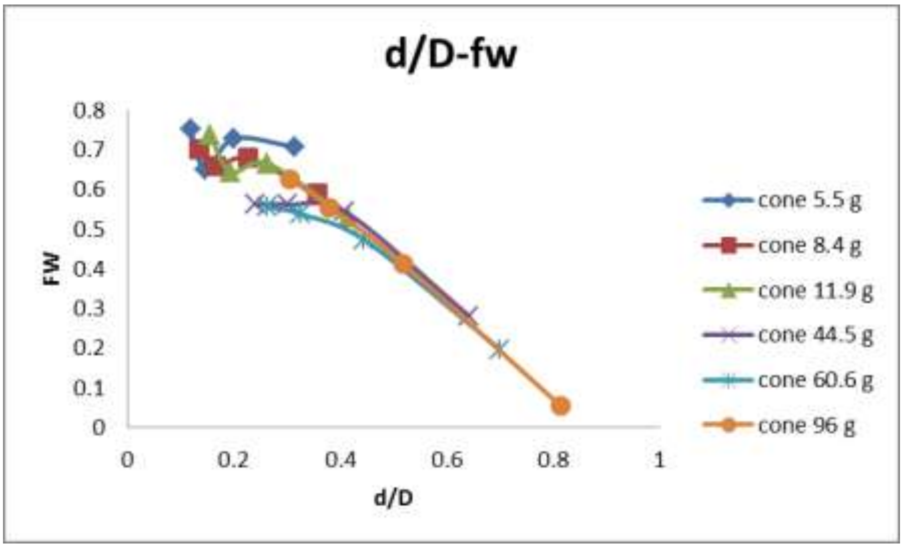


Figure (51): Relationship between (FW-d/D) for falling cone in cmc

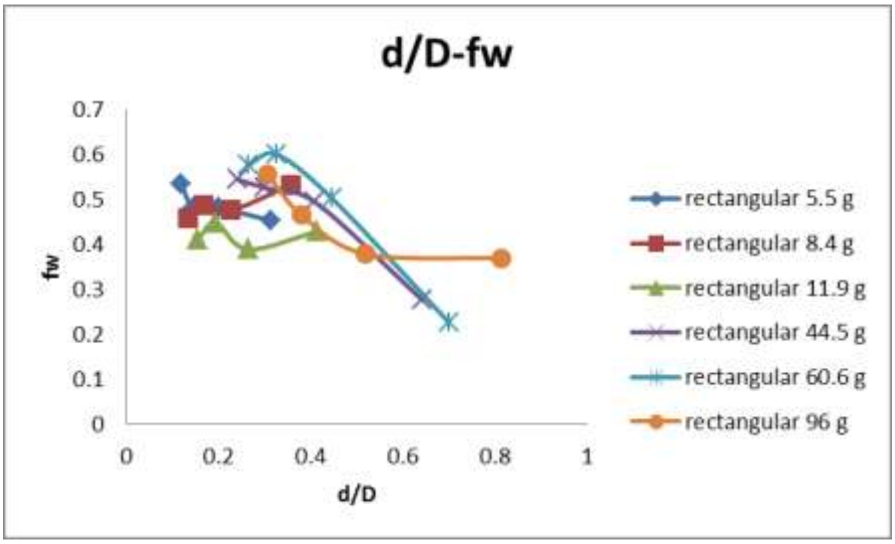
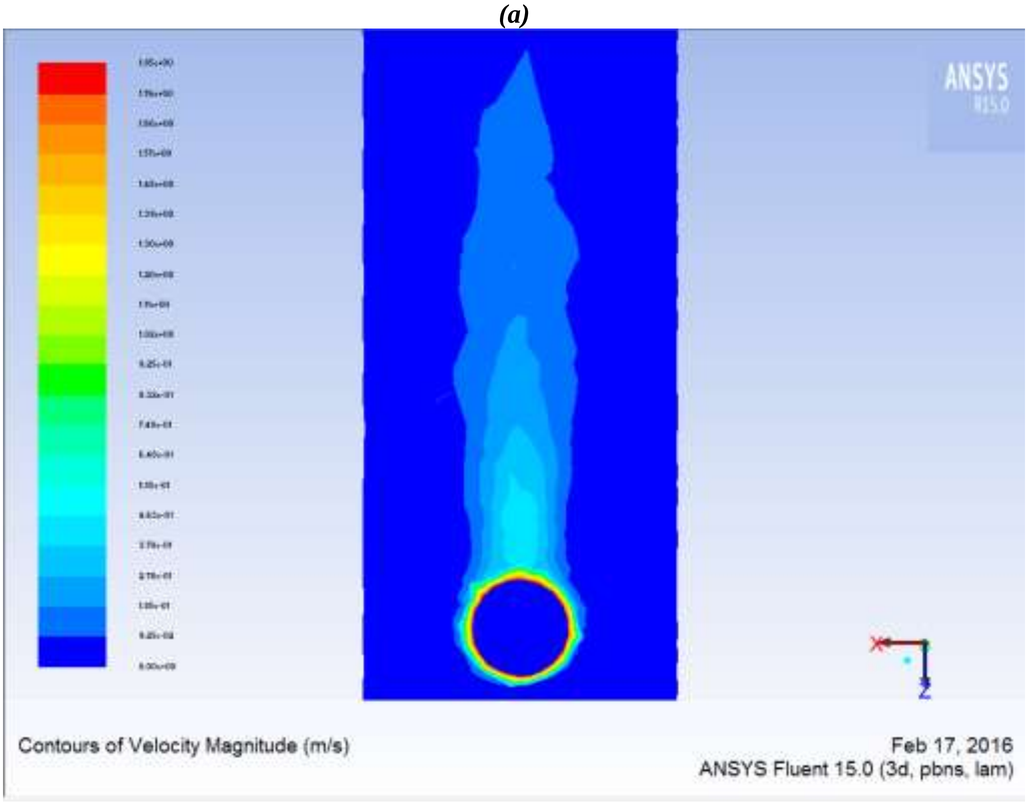


Figure (52): Relationship between (FW-d/D) for falling rectangular in cmc

Wake Characteristics Behavior

From figures (53)up to(57) show the simulation for experimental data for particles having weight 96g falling in diameter tube (10 cm,8cm,6cm,4cm).This simulation given insight for the velocity profile contours for the flow the effect of finite wall on the particle surface in fluid are subjected to higher shearing .The wake characteristics described by recirculation length that measure from the rear of the particle at low Reynolds number the flow remains attached to the particle surface also recirculation length in non- Newtonian greater than Newtonian fluid because shear thinning behavior also the width of boundary layer decrease with increasing diameter. The non-Newtonian fluid show large wake region because the boundary layer is laminar also in Newtonian fluid the wake region is smaller because the separation delayed and the flow for boundary layer turbulent.

(a)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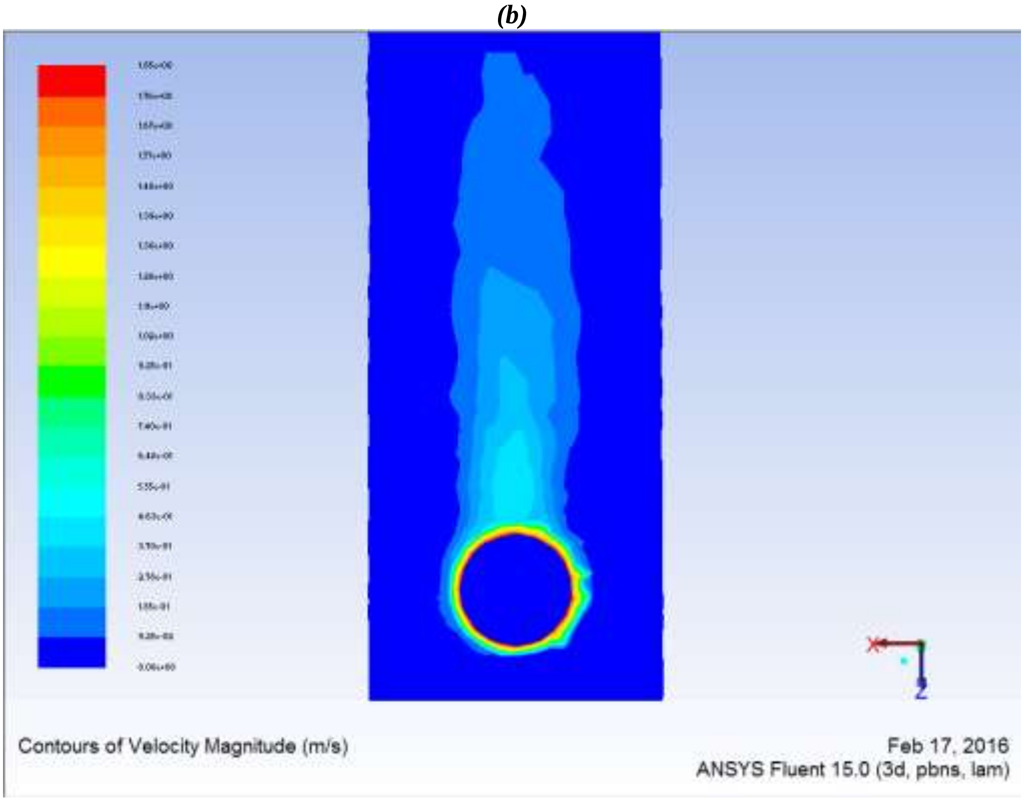
Contours of Velocity Magnitude (m/s)
Feb 17, 2016
ANSYS Fluent 15.0 (3d, pbns, lam)

(b)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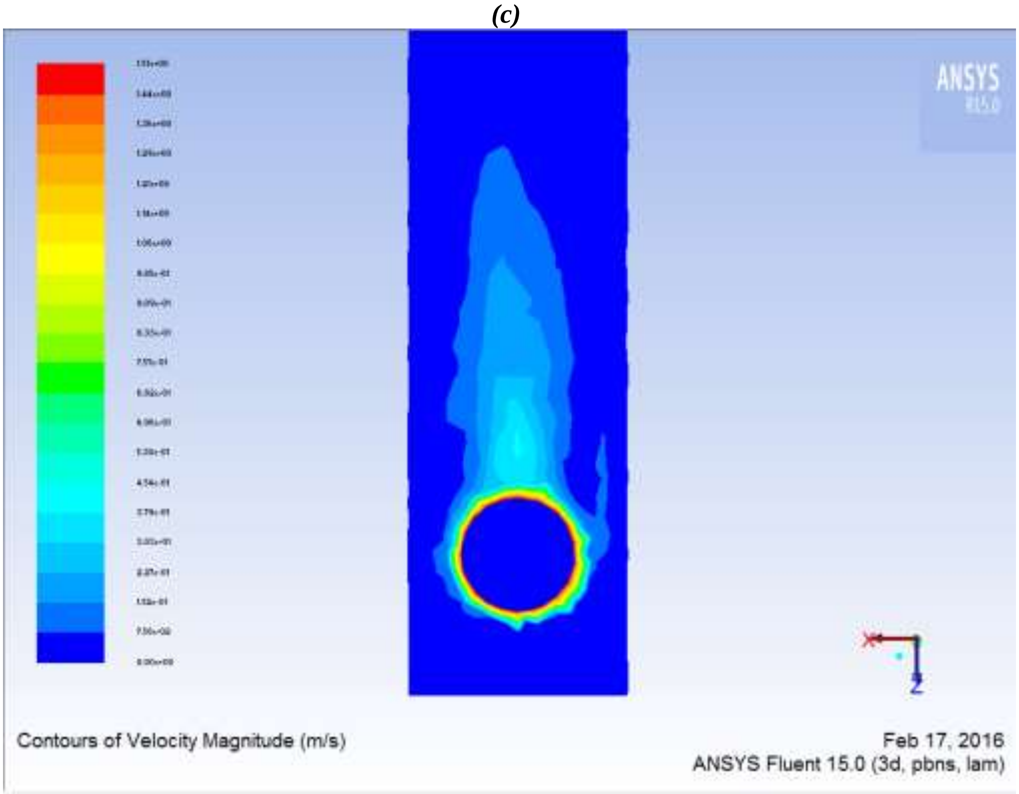
(c)



(d)

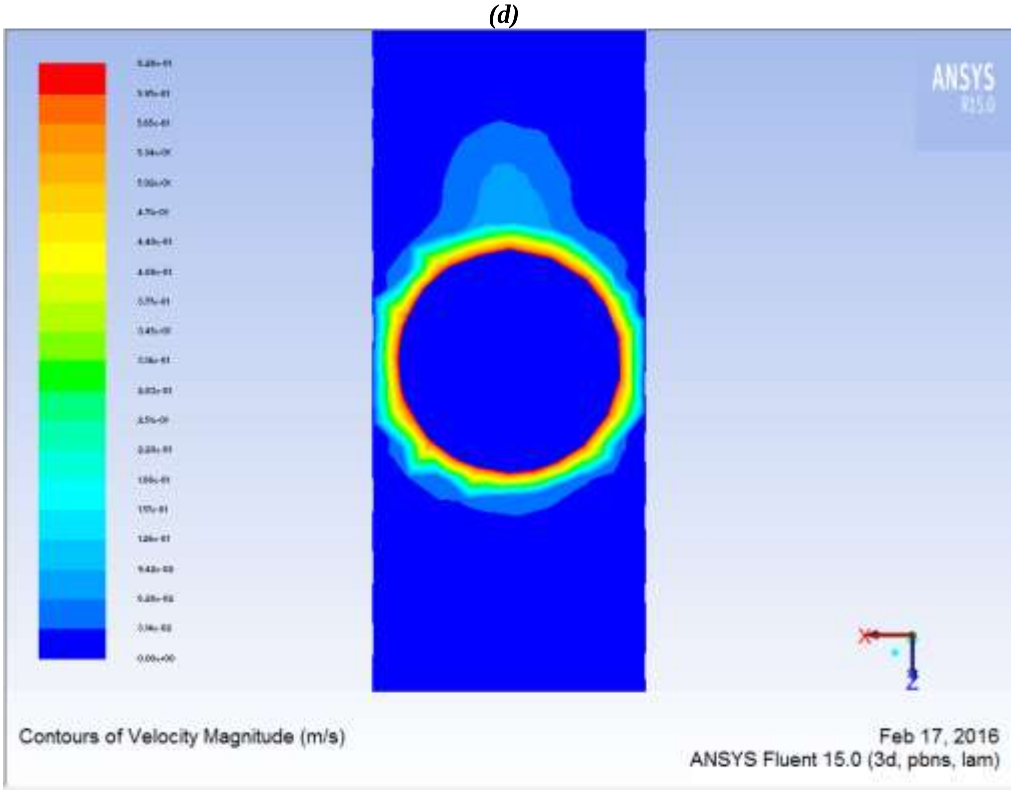
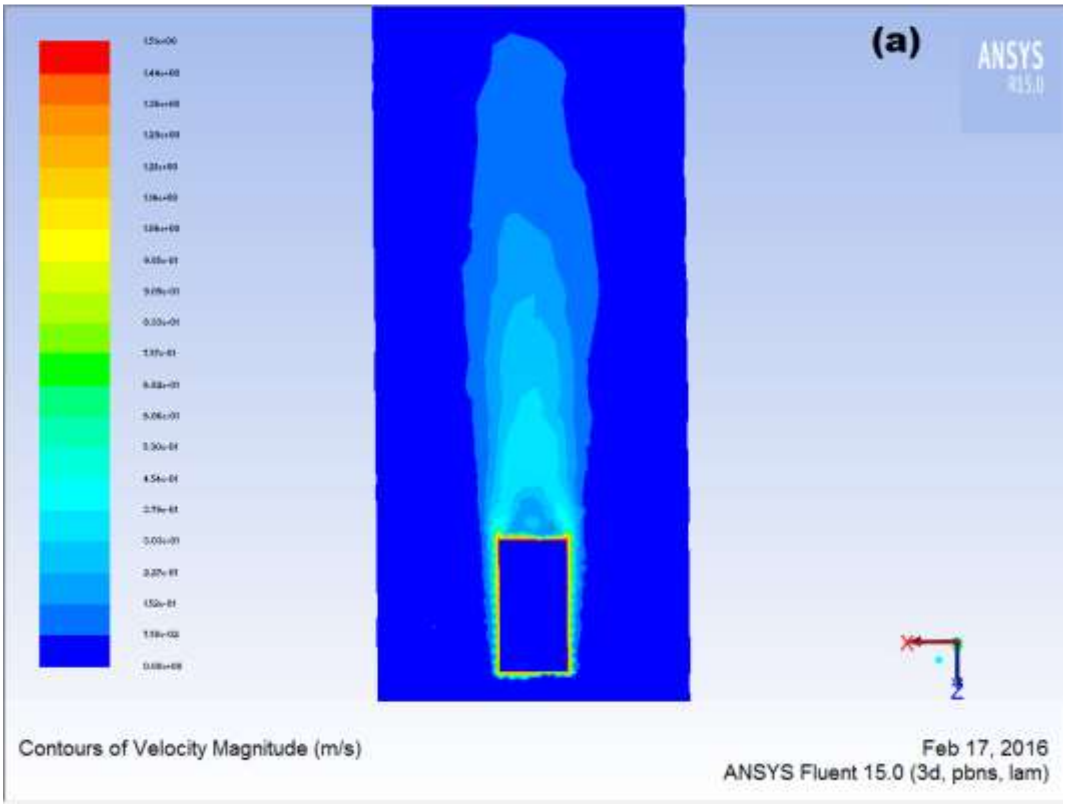
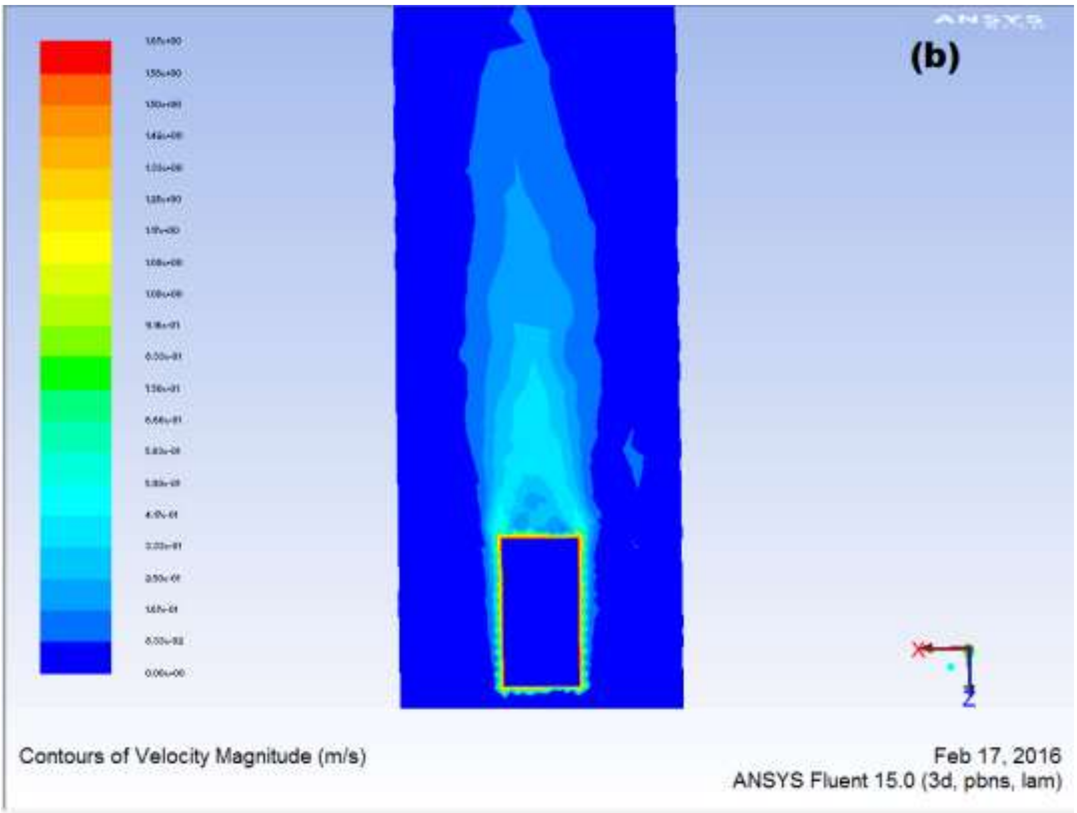


Figure (53): sphere 96 g falling in four tube in cmc (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm


(a)
ANSYS
R15.0
Contours of Velocity Magnitude (m/s)
Feb 17, 2016
ANSYS Fluent 15.0 (3d, pbns, lam)


(b)
Contours of Velocity Magnitude (m/s)
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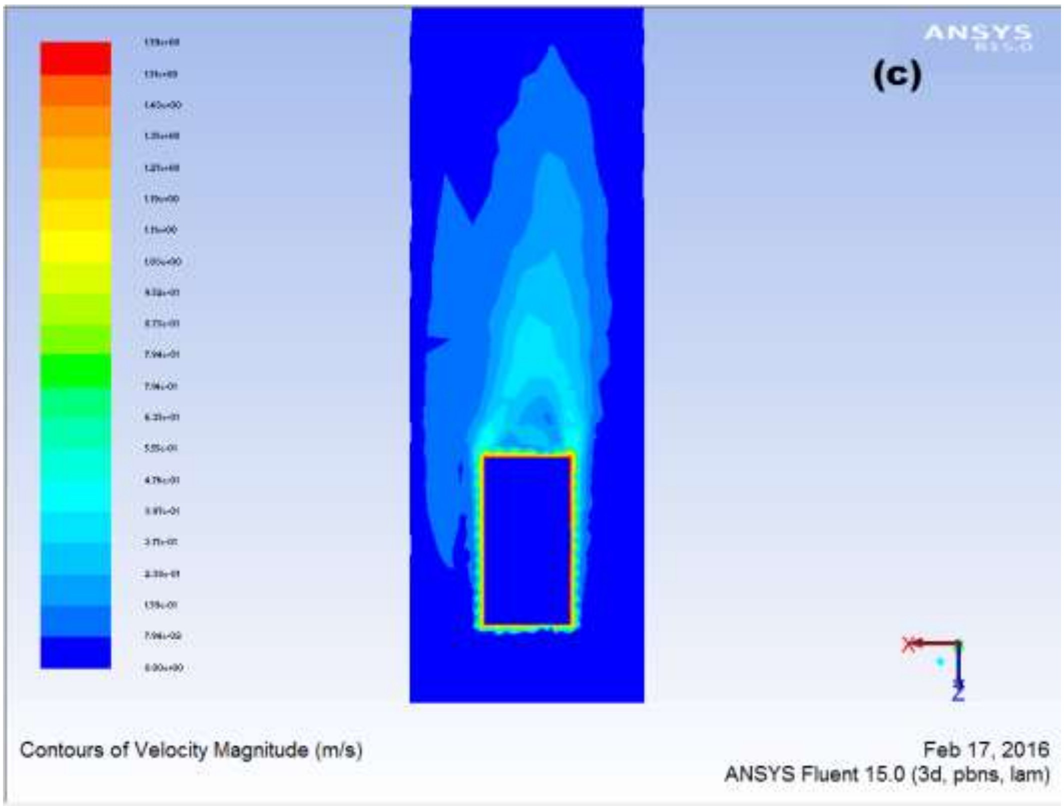


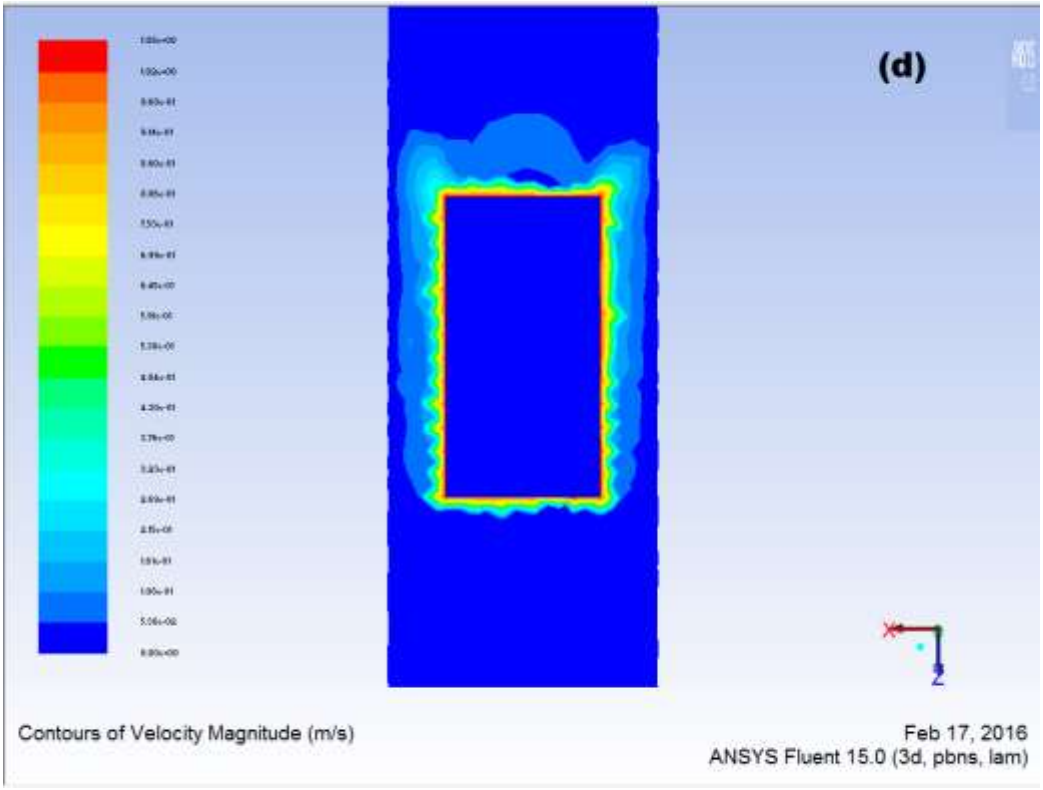
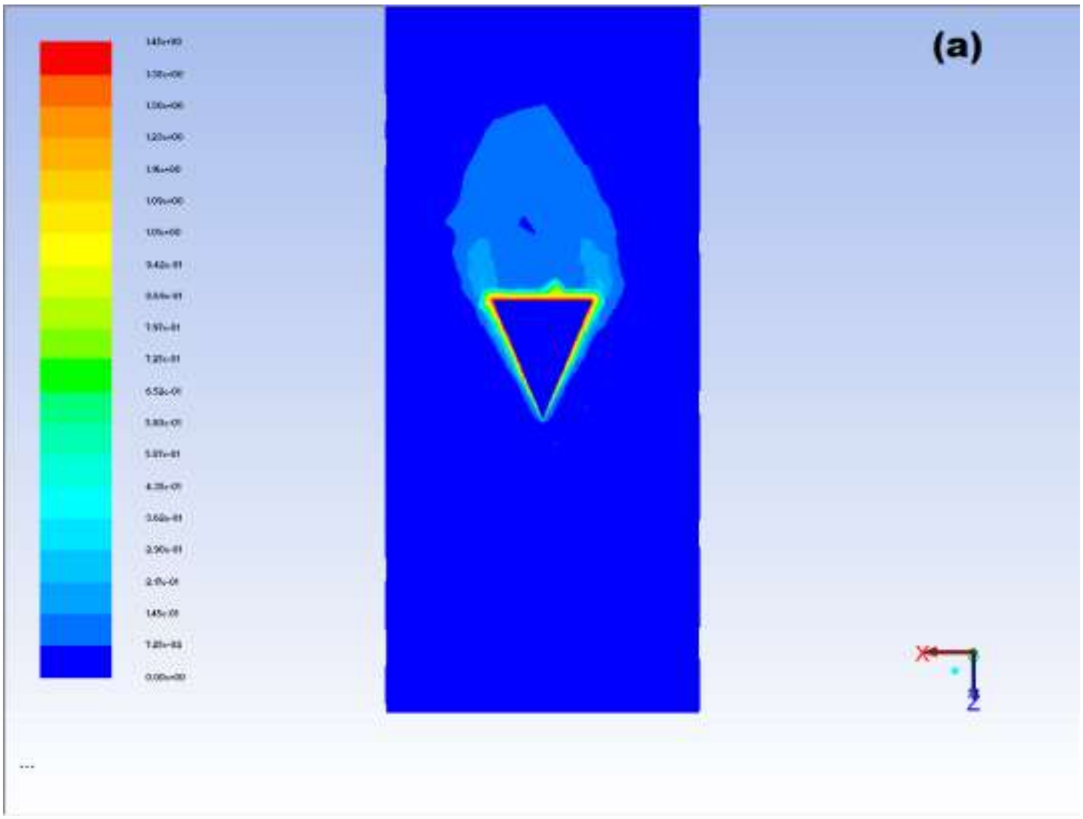


Figure (54): cylinder 96 g falling in cmc in four tube (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm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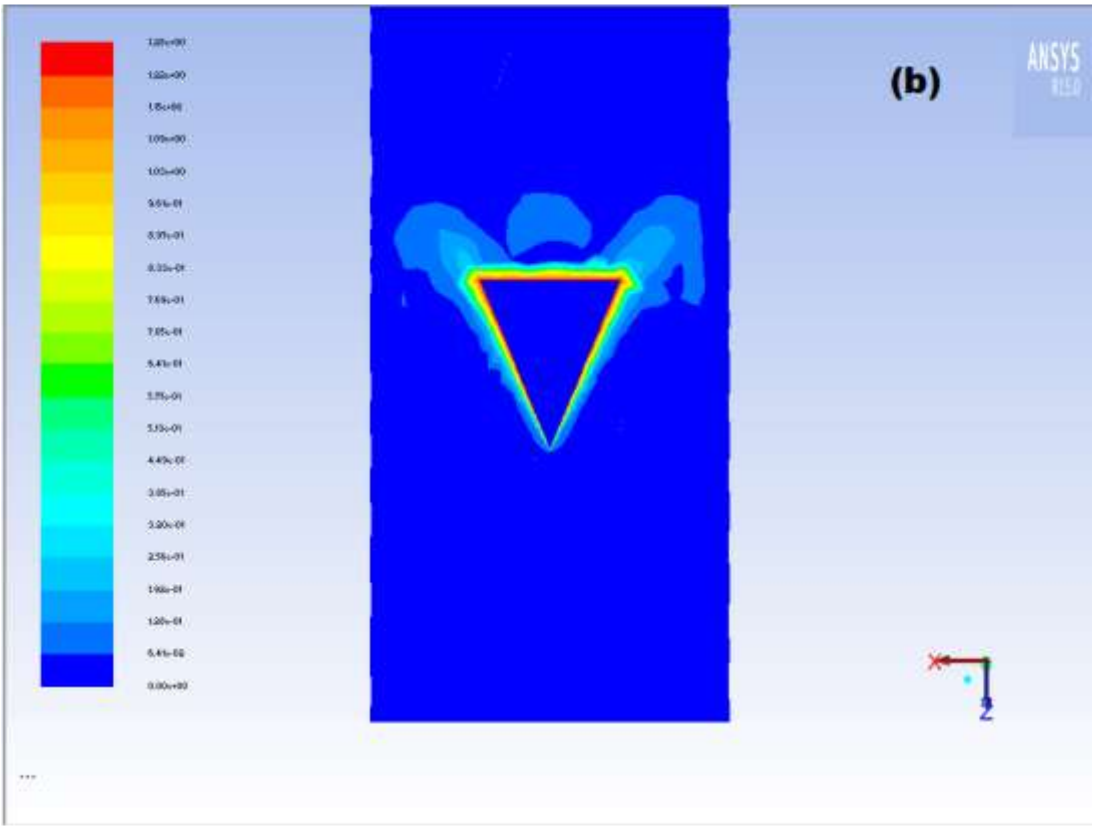
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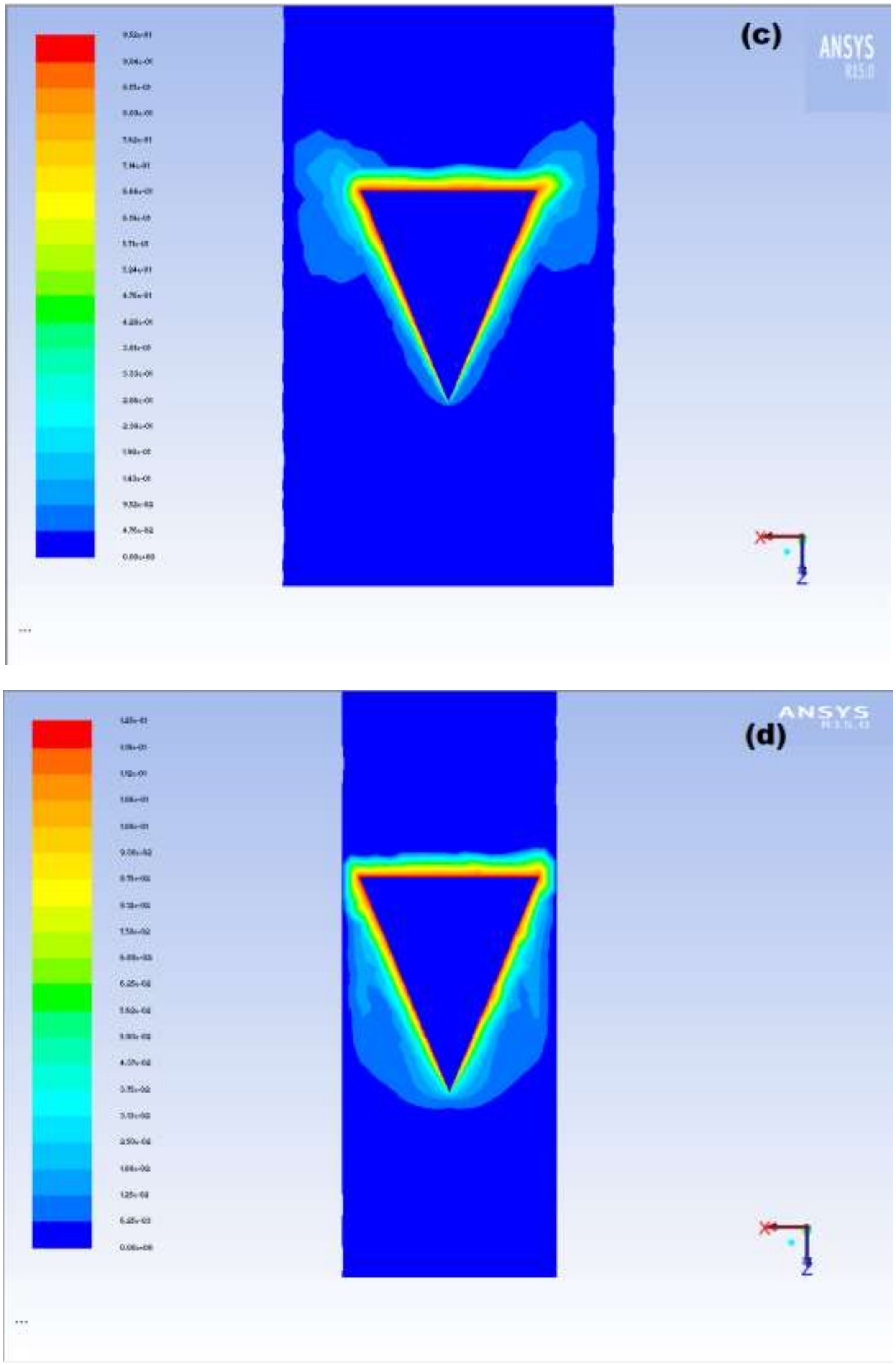

Figure (55): cone falling in four tube in cmc (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

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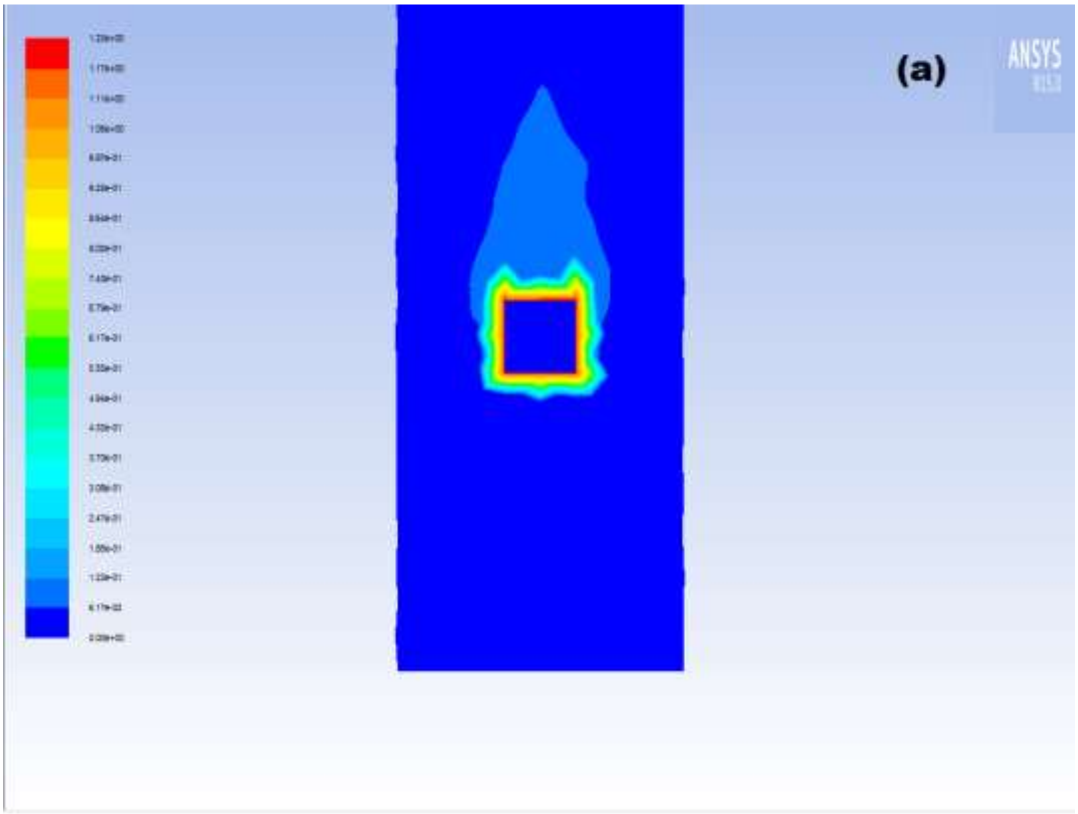

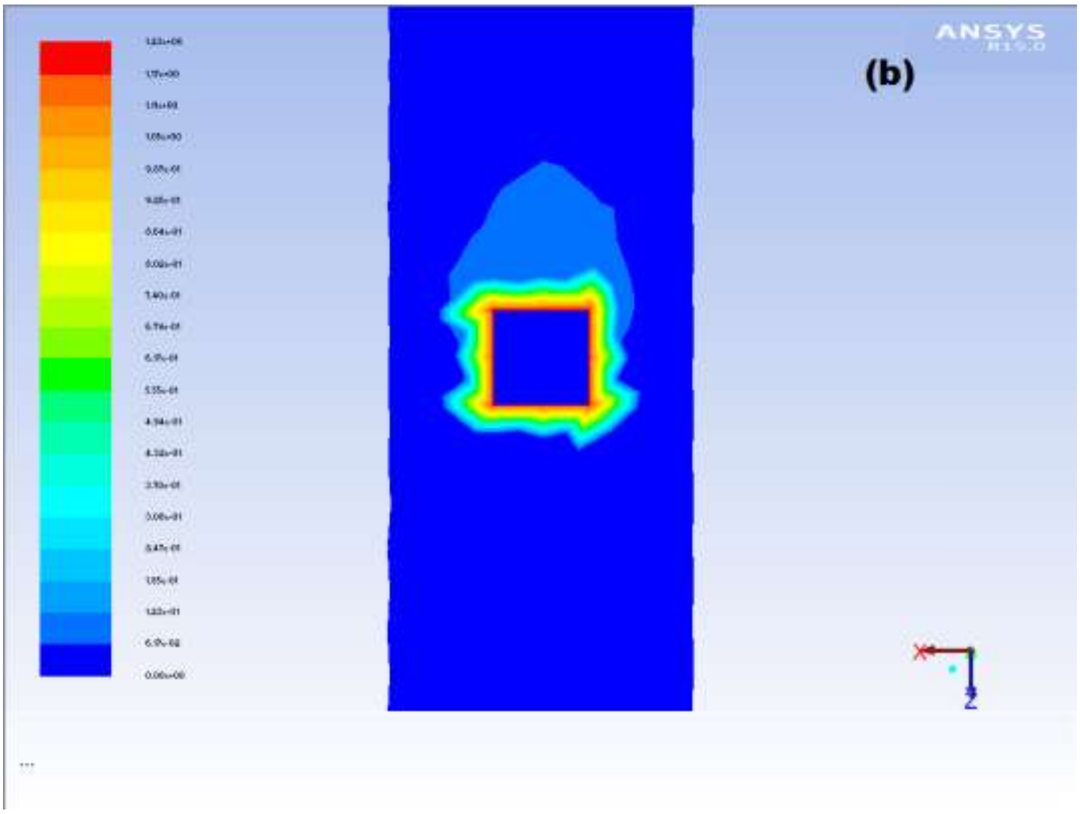

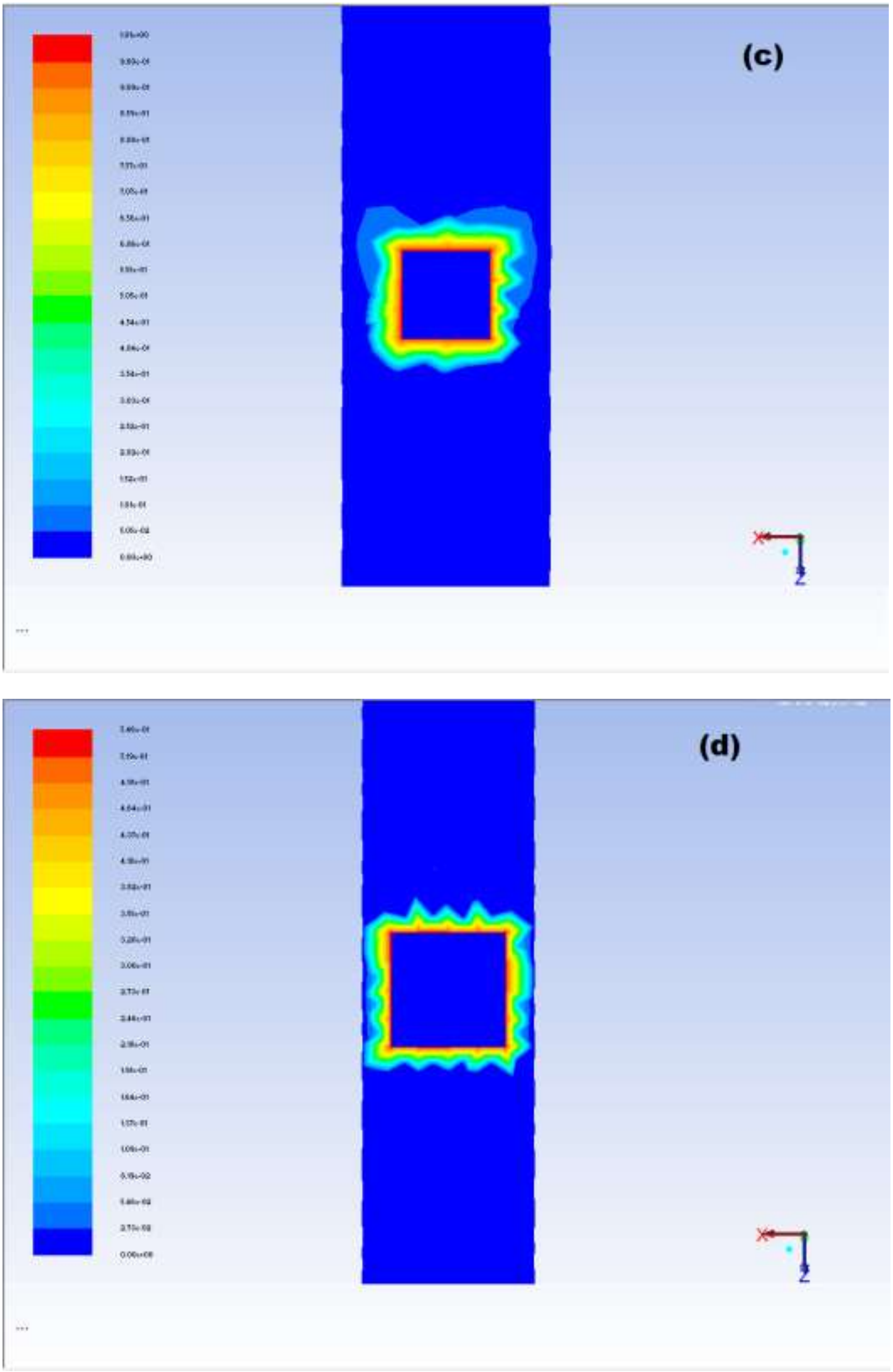

Figure (56): cube 96 g falling in four tube in cmc (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

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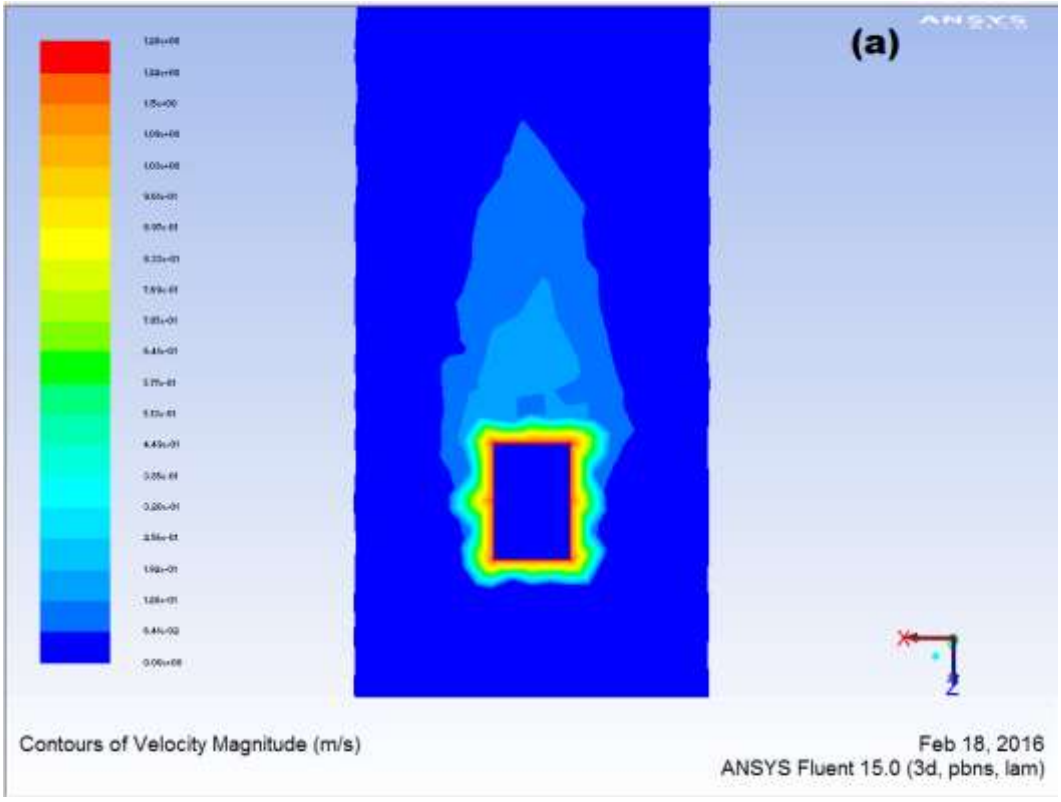

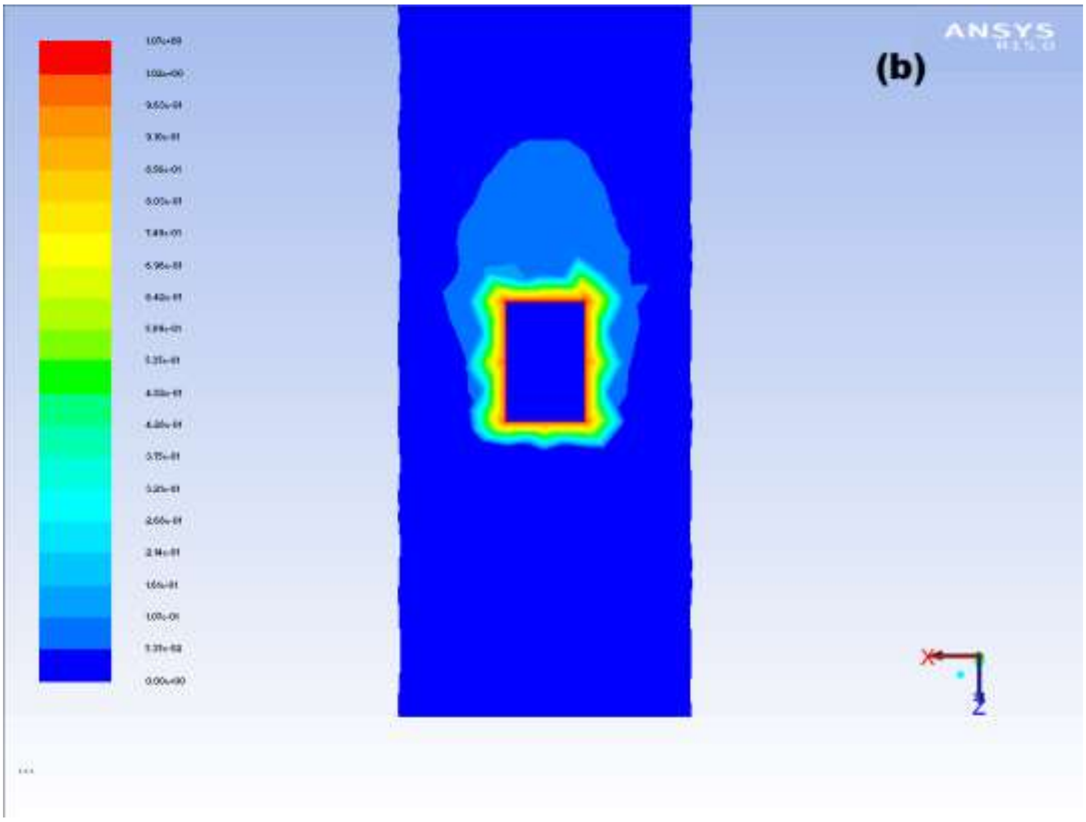

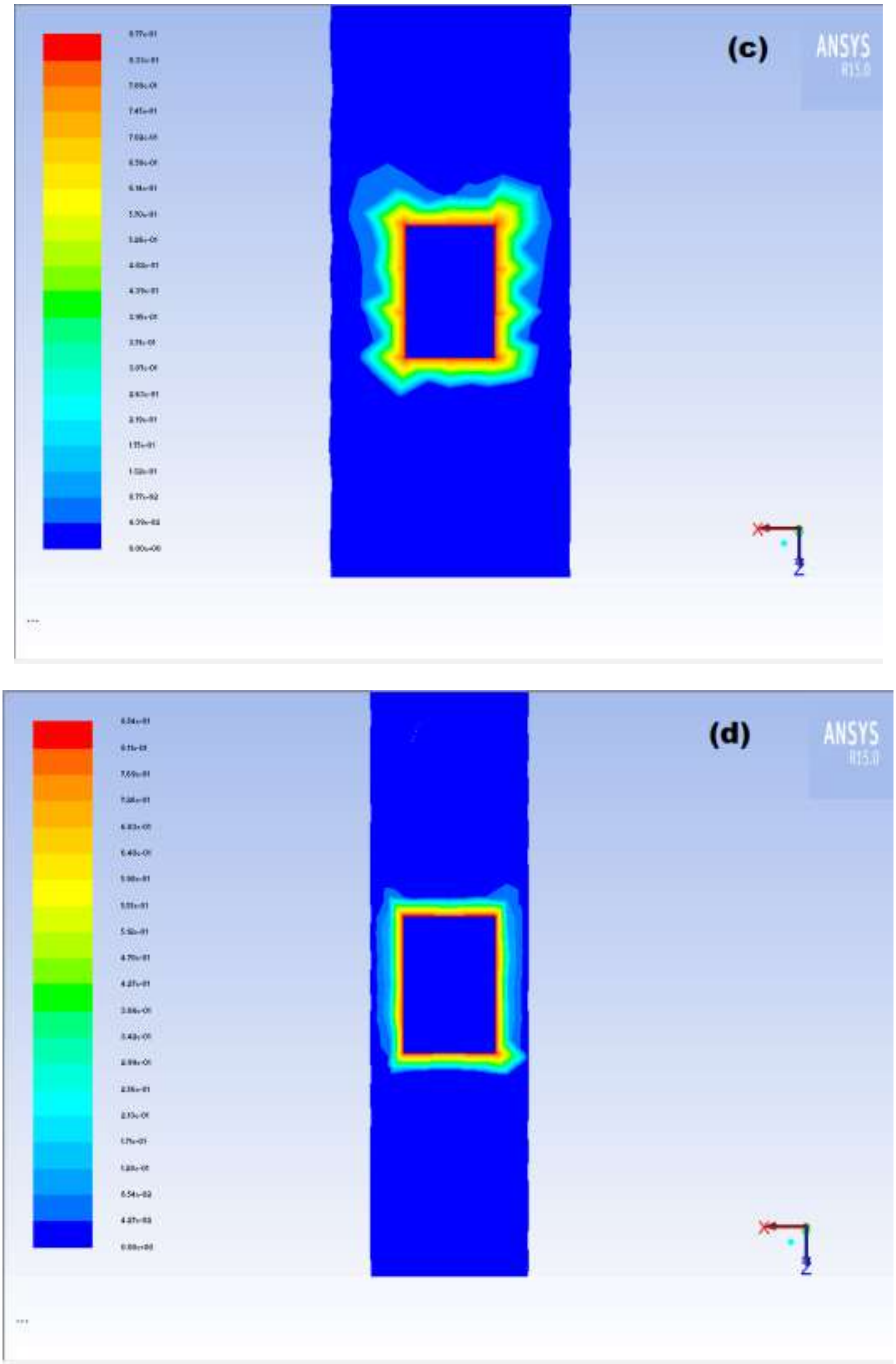

Figure (57): rectangular falling in four tube in cmc (a) tube 10cm (b) tube8 cm(c) tube 6 cm (d) tube 4 cm

CONCLUSION

Newtonian Fluid

1. Drag coefficient is passed in turbulent slip regime.
2. The drag coefficient approximate constant for spherical particle and depended on sphericity for non-spherical particle.
3. Drag coefficient independent on Reynolds number.
4. Drag coefficient depend on sphericity
5. Less value for wall correction factor having higher wall effect
6. The wall correction factor decrease with increasing diameter ratio.
7. Drag coefficient increase with increase diameter ratio but this increasing is small and not significant.

Non-Newtonian Fluid

1. Drag coefficient in non-Newtonian fluid is passed in laminar slip regime
2. With increasing particle Reynolds number, the drag coefficient of particle will decreased
3. The rheological properties of non- Newtonian fluids have a higher effect on drag coefficient and wall effect, because as the fluid became far from Newtonian behavior, (flow index n far from unity, n=0.736), the drag coefficient and wall effect will be decreased.
4. Drag coefficient increase with increasing diameter ratio and appearing more significant.

LIST OF SYMBOLS

β: diameter ratio for sphere diameter to tube diameter(d/D)
v : $settling$ Velocity in bounded medium(m^2/s)
v_∞: settling velocity in an unbounded medium(m^2/s)
CD : drag coefficient in bounded medium
dp : equivalent diameter for particle(m)
Dc : diameter for circular cross section area tube (m)
Fw : wall correction factor
Re : Reynolds number
K_1, K_2 : Stoke factor ,Newton factor
g : Gravitational acceleration, m/s²

GREEK LETTERS

ρ:density (kg/m^3)
ᴍ:viscosity (pa s)
ρ_p : *Density of sphere, kg/m³*

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