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NUMERICAL SIMULATION FOR WALL EFFECT ON A SPHERICAL PARTICLE SETTLING IN CIRCULAR AND NON-CIRCULAR DUCTS FILLED WITH NEWTONIAN FLUID

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KEYWORDS: wall effect, drag, settling, Newtonian fluid.

ABSTRACT
The objective of this research is to study the wall effect on a spherical particle settling in circular tube and square tube cross section area and compared between them. The effect of bounded wall on drag coefficient expressed by taken a sphere settling along the axis of tubes .The governing equations and the boundary conditions for two types of tubes numerically solved by using Ansys fluent 15 software over a wide range for conditions ,sphere to tube diameter ratio: B(0.1-0.6),Reynolds number:(10-110).One type of shape rigid solid particle was used :sphere settling in two types of container one circular and other non-circular cross section taken square cross section as non-circular tube .Equivalent diameter was used for an equal area circular cylinder to evaluate diameter for square container in this study taken equal area and diameter ratio for circular and square cross section area tube .One type of fluid was used in this study :Newtonian fluid such as water .The results shown that the drag coefficient decrease with increasing Reynolds number because the flow in laminar slip region ,the drag coefficient increase with increasing in the diameter ratio because the present of the bounded wall lead to increase in drag force .The square cross section area tube having drag force greater than circular cross section area tube.

INTRODUCTION
The finite wall produced a retarding effect on a particle falling in Newtonian fluid at the axis of circular and non-circular cross section area tubes .In this study used sphere as particle settling in stagnant Newtonian fluid .The wall effect on the particle motion can be expressed in different ways :as the drag force in finite fluid to infinite fluid ratio ,velocity ratio for bounded to unbounded medium ,viscosity ratio and drag coefficient ratio ,thus the wall effect typically represented in term of wall correction factor $v_t/v_{t\infty}$, $f_d/f_{d\infty}$, CD/CD_∞ ,…The effect for finite wall and the shape of cross section area for container is very important in different applications such as electrostatic precipitation ,particle separation ,falling ball viscometer .,[1] This investigation is important in different field chemical and mechanical as well as environmental engineering in the last field application in treatment water processes(sedimentation ,flocculation , and filtration),[2] It is known that the finite walls cause retardation force on particle settling in Newtonian fluid this happen back to the upward flux of the water this volume for flux equal to the volume of particle .The information now available for wall effect on motion for sphere in Newtonian fluids ,now it is possible to calculate the wall correction factor under most conditions of particle interest the value for sphere to tube diameter ratio and sphere Reynolds number ,[3,4,5,6] .Caswell (1970),[7],carried out a perturbation analysis for the creeping motion of a sphere in a Rivlin-Ericksen model fluid in a cylindrical vessel and predicted the wall effect of to be less severe than those in Newtonian fluids also the study for the effect of presence of finite wall on the drag force by using Carreau model fluid and letting the spherical particle settling along the axis of cylindrical tubes .[8]for simple calculation consider that the particle is set and the cylinder walls are moving with fluid velocity .[9] For results obtained in square vessels the diameter of an equal area circular cylinder was used in calculating diameter ratio.[10]

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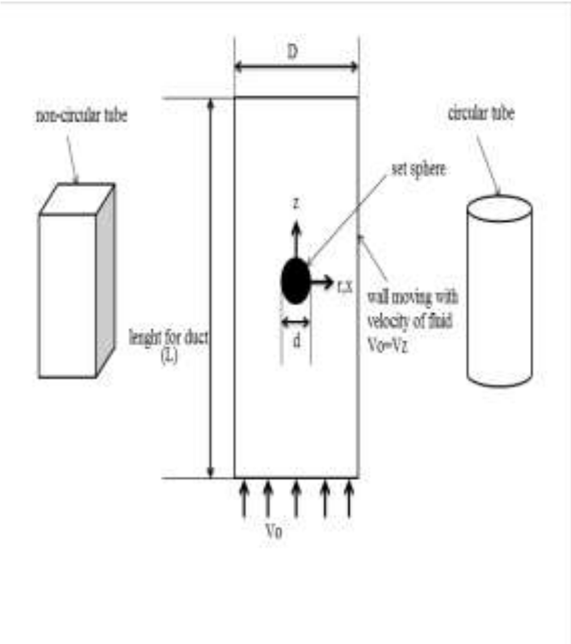


Figure (1): the flow around the sphere in circular and non –circular ducts.

MATHEMATICAL MODELING

Consider a sphere with diameter (d) located at the axis of the circular and non-circular tube the circular tube having diameter (D) and the non-circular tube taken square cross section area having equivalent diameter to circular cross section area (dc) as shown in figure(1) .to solve the problem for settling particle in stagnant fluid this case the same behavior for the fluid moving at uniform velocity (Vo)and the particle set in the axial of tube also the wall for tube move upwards at the same velocity (Vo).

The governing equations:

Continuity equation;

$\nabla . v = 0$ (1)

Momentum equation;

$\rho v . \nabla v = -\nabla p + \nabla . \tau$ (2)

Where v: the velocity vector,

P: pressure ,ρ: density ,τ: stress tensor

The boundary condition for the flow for circular cross section tube:

1-Inlet

$v_r = 0 , v_z = v_o$

2-Outlet

$p = 0 , \frac{\partial v_z}{\partial z} = 0$

3- Symmetry

$v_r = 0$

4- Sphere wall

$v_r = v_z = 0$

5- tube wall

$v_r = 0 , v_z = v_0$

The boundary condition for the flow for square cross section tube :

1-Inlet

$v_x = 0 , v_z = v_o$

2-Outlet

$p = 0 , \frac{\partial v_z}{\partial z} = 0$

3- symmetry

$v_x = 0$

4- sphere wall

$v_x = v_z = 0$
5- tube wall
$v_x = 0 , v_z = v_0$
The above governing equation with the boundary condition are solved numerically .It is useful to introduce some dimensionless parameters such as drag coefficient and Reynolds number.
The sphere Reynolds number is defined as;
$Re = \frac{\rho\, ud}{\mu}$ (3)

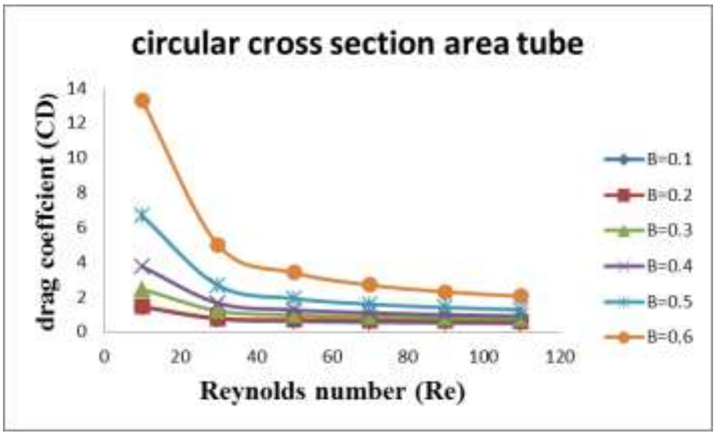
The drag coefficient defined as;
$CD = \frac{f_d}{\frac{1}{2}\rho u^2 \frac{\pi}{4} d^2}$ (4)
Wall correction factor defined as;
$fw = \frac{drag\ in\ bounded}{drag\ in\ un\ bounded}$ (5)
Or ; $fw = \frac{CD}{CD_\infty}$

The corresponding value of drag coefficient in an unbounded medium CD_∞ was calculated by extrapolating the plot between drag coefficient and diameter ratio to (B=d/D=0). A knowledge of the unbounded medium drag coefficient allows the calculation of the wall correction factor.

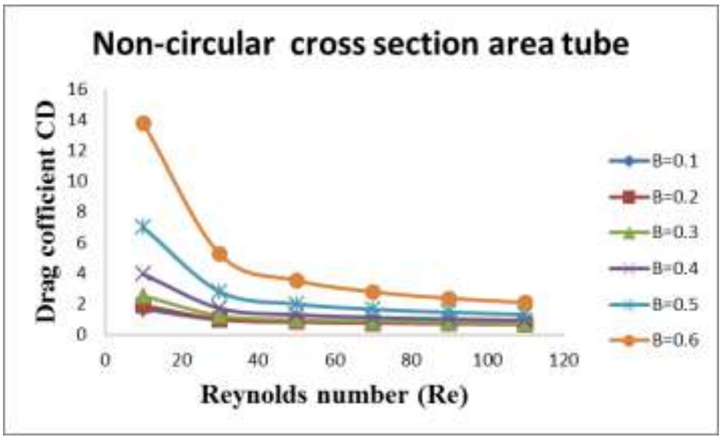
USING ANSYS FLUENT 15
The numerical solution solved in this program. Auto cad 14 used to draw the zone tube and particle and then import in to Ansys fluent .Also consider the simulation happen under isothermal condition .The flow domain meshed using the sizing relevance center medium and smoothing in high. The solution built in steady and Newtonian flow models by using (laminar (viscous) flow).Water used as Newtonian fluid. Then run calculation at number of iteration equal to (1000). The accuracy of the numerical solution depend on the domain and mesh.

RESULTS AND DISCUSSION
In this study numerical simulation have been carried for the following (n=1)power law index for Newtonian fluid ,10<Re<110,and 0.1<B<0.6 ,Also two types for cross section area circular and square tube then compared between them.

4.1 Effect of Reynolds number on drag coefficient
Figure (2) shown the drag coefficient depend on Reynolds number and decrease with increasing Reynolds number because the flow in laminar region and the inertial force is more significance in this region .



(a)

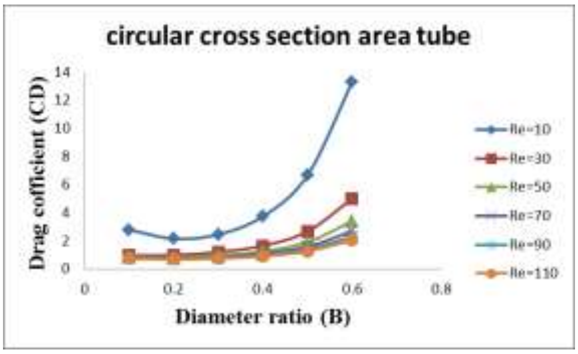


(b)

Figure (2):the relationship between drag coefficient and Reynolds number depend on diameter ratio (B) in circular and non-circular cross section area ducts(a)and(b).

4.2 Effect for diameter ratio on drag coefficient

The drag coefficient in the bounded wall is greater than unbounded medium, drag coefficient increase with increasing of diameter ratio this return to steeper velocity gradient around the sphere surface also this effect decrease with increasing Reynolds number as shown in figure (3) for circular cross section area tube and the same behavior for square cross section area tube.



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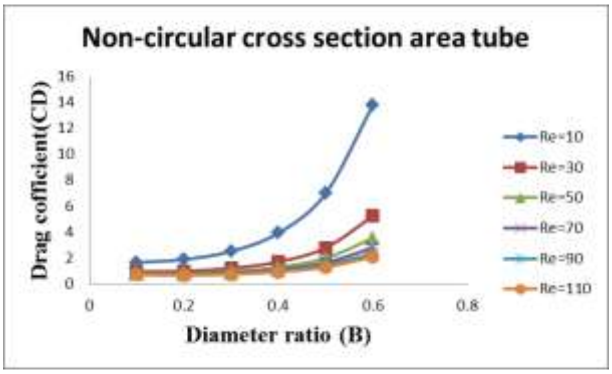


(b)

Figure (3): relationship between drag coefficient and diameter ratio depend on Reynolds number in circular and non-circular cross section area tube (a) and (b).

4.3 Compared drag coefficient between circular tube and square tube

The drag coefficient increase with increasing diameter ratio for both circular and square cross section area tube. The square cross section area tube having drag coefficient greater than in circular cross section area tube because the distance between sphere surface and the wall tube surface in non-circular tube less than circular tube for the same area and diameter ratio this lead the drag coefficient increase shown this result in table (1)and table (2).

Table (1): numerical result for circular cross section area tube.

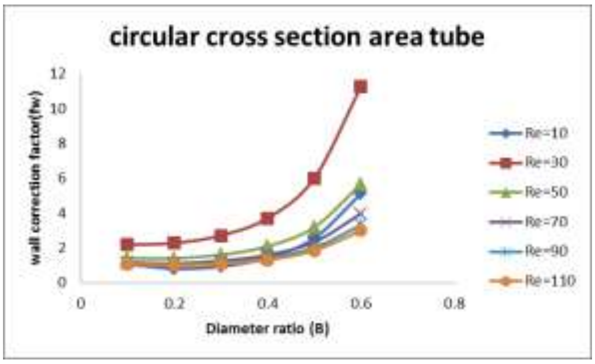
Re	CD					
10	1.435	1.466	2.459	3.748	6.6703	13.288
30	0.733	0.782	1.212	1.655	2.6732	5.002
50	0.613	0.703	0.9708	1.264	1.9155	3.398
70	0.5575	0.654	0.8639	1.0899	1.5918	2.692
90	0.5216	0.631	0.799	0.9842	1.4023	2.30199
110	0.494	0.574	0.7544	0.907	1.2732	2.0497
B	0.1	0.2	0.3	0.4	0.5	0.6

Table (2): numerical result for non-circular cross section area tube.

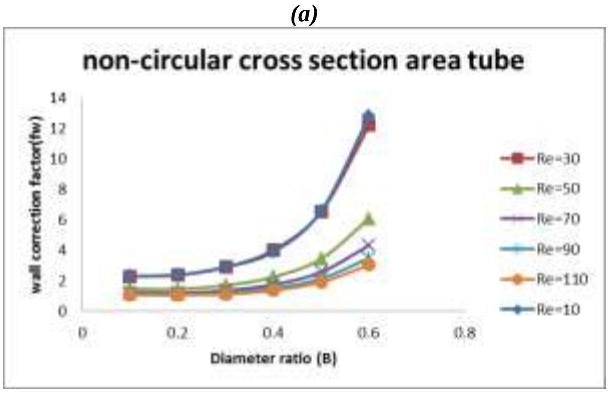
Re	CD					
10	1.475	1.9108	2.545	3.9486	6.993	13.759
30	0.737	0.995	1.243	1.73	2.8155	5.2514
50	0.6134	0.8286	0.993	1.316	2.012	3.549
70	0.558	0.7612	0.883	1.1367	1.666	2.807
90	0.530	0.7238	0.817	1.0293	1.467	2.3858
110	0.510	0.696	0.769	0.9526	1.33	2.108
B	0.1	0.2	0.3	0.4	0.5	0.6

4.4 effect of diameter ratio on wall correction factor

The wall correction factor increase with increase the diameter ratio and decrease with increasing the Reynolds number because the retarding effect increase with increasing the diameter ratio and the wall effect become more significant as shown in figure (4).



(a)

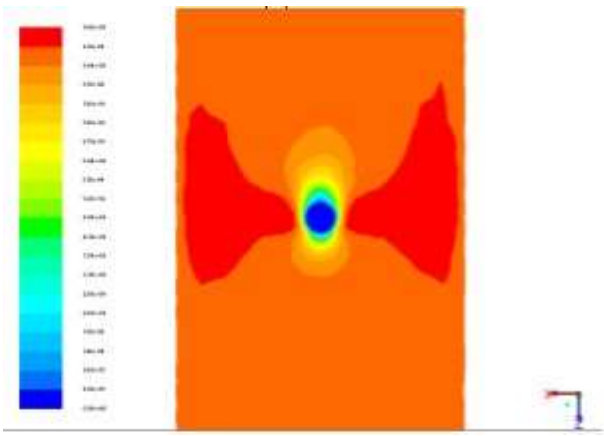


(b)

Figure (4): relationship between wall correction factor and diameter ratio in circular and non-circular tube (a) and (b).

4.5 velocity profile contours

The velocity field for the boundary layer contours can be calculated from the fluent program the figure (5) shown a set of simulation and describe the behavior for boundary layer in different diameter ratio from(B=0.1-0.6) and (Re=10)the flow remain attached to the sphere surface because the flow is laminar and the velocity filed for the boundary layer around the sphere particle decrease with increasing the diameter ratio because the drag force increase and the drag coefficient increase this behavior same for circular and non-circular cross section area tube. This behavior shown in figures below and given more insights for the flow field by using same value for Reynolds number with different diameter ratio.



(a)

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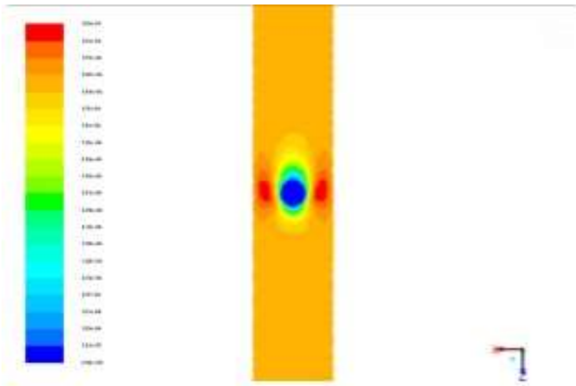

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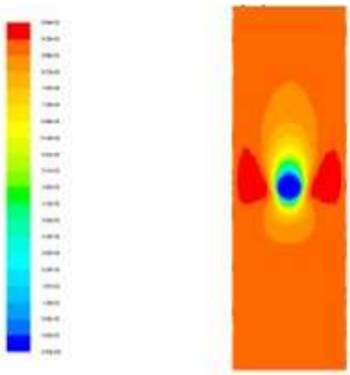

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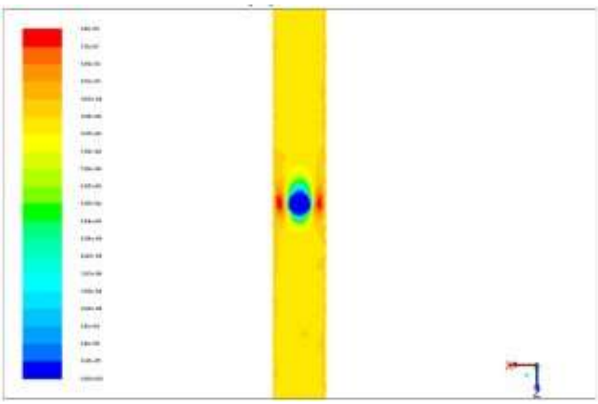

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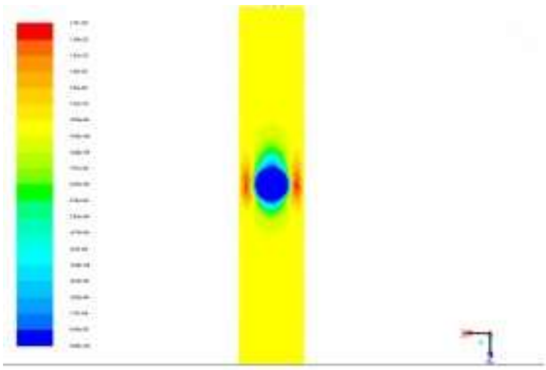

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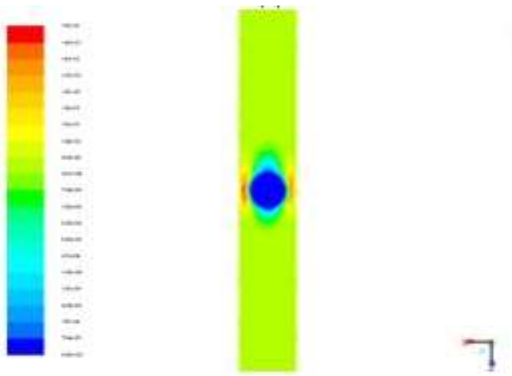

(f)

Figure (5): shown velocity profile contour for Re=10 with different diameter ratio (a) B=0.1 (b) B=0.2 (C)B=0.3(d)B=0.4(e)B=0.5(f)B=0.6

CONCLUSIONS

1. The drag coefficient decrease with increasing the Reynolds number for circular and non –circular cross section area tube.
2. The drag coefficient increase with increase diameter ratio for circular and non-circular tube.
3. The wall correction factor increase with increase diameter ratio.
4. The wall correction factor decrease with increase Reynolds number.
5. The drag coefficient in square cross section greater than circular cross section area tube for the same area and diameter ratio.
6. The velocity filed for boundary layer or the length recirculation decrease with increase diameter ratio.

LIST OF SYMBOLS

B : diameter ratio for sphere diameter to tube diameter
v_t : $terminal$ velocity in bounded medium(m^2/s)
$v_{t\infty}$: terminal velocity in an unbounded medium(m^2/s)
f_d : drag force in bounded medium (N)
$f_{d\infty}$: drag force in an unbounded medium(N)
CD : drag coefficient in bounded medium
CD_∞ : drag coefficient in an un bounded medium
d : diameter for sphere particle(m)
D : diameter for circular cross section area tube (m)
d_c: diameter for square cross section area tube with area equal to circular cross section (m)
P : pressure (N/m^2)
Fw : wall correction factor
Re : Reynolds number

GREEK LETTERS

ρ:density (kg/m^3)
ʍ:viscosity (pa s)
u:settling velocity (m^2/s)

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