© 2019 IJSRSET | Volume 6 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET

Hydrodyamic Study of Newtonian Fluid Flow Over A Sphere Using CFD Models

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ABSTRACT

The objective of this project is modeling and simulation of a sphere rolling down an incline with constant angular velocity in an incompressible Newtonian media by using CFD techniques. Study on the hydrodynamics of the Newtonian fluid flow over the sphere has also been done. Comparison of velocity has been done for various types of fluids. Comparison of velocity has also been done for several angles of inclination and the angular velocity of the ball is also changed for each of these cases. Analysis and discussion of the motion of the sphere has been done using velocity contours.

Keywords : Newtonian Media, Hydrodynamics, Modeling, CFD

I. INTRODUCTION

A Newtonian fluid is one in which at a given temperature and pressure, the shear rate increases linearly with shear stress for a wide range of shear rates. As the shear stress tends to reduce the fluid flow near the centre of the pipe and accelerates the slow moving fluid towards the walls, for some radius within the pipe it is acting simultaneously in the negative direction on the fast moving fluid and in the positive direction on the slow moving fluid. There are several forces which affect the hydrodynamics of a Newtonian fluid among which drag force and wall effect are prominent.

II. Simulation and Execution

a. PROBLEM DESCRIPTION

Consider a small, spherical, non-deformable particle of diameter D, mass m and density ρs rolling down a smooth plane in an infinite extent of an incompressible Newtonian fluid of density ρ and viscosity μ. Let u represent the velocity of the particle at any instant time, t, and g the acceleration due to gravity. Fig 1 demonstrates a schematic figure of current problem. Neglecting lift force and sphere tube friction, the equation of motion is gained as follows.

$$m(1.4+ 2\,\rho/\rho_s)du/dt = mg(1- \rho/\rho_s)\sin(\theta) - 1/8\pi D^2\rho C_D u^2$$

where C_D represents the drag coefficient. In the right hand side of the Eq. the first term represents the buoyancy affect and the second one corresponds to resistance, drag, and force. The main difficulty in solution of Eq. lies in the non-linear terms which are generated due to non-linearity nature of the drag coefficient, CD. Substituting in Eq. and by rearranging parameters, Eq. could be rewritten as follows

$a\,du/dt + bu + cu^2 - d = 0$, $u(0)=0$

where ,

$a=m(1.4 + 2\,\rho/\rho s)$

$b= \beta\pi D\mu/ 8$

$c=\alpha\pi D^2\rho/ 8$

$d=mg(1- \rho/\rho s)\sin(\theta)$

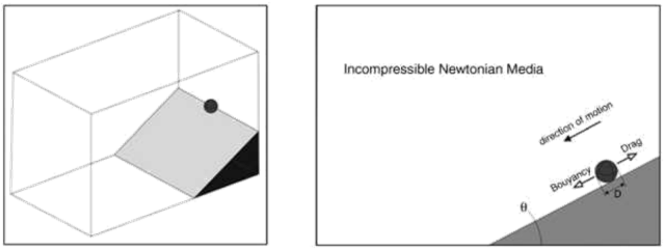

Figure 1. Schematic picture of a spherical particle rolling down a smooth inclined plane in a Newtonian media (Jalaal M et al .2009)

The present problem involves the design of an inclined plane in an incompressible Newtonian media where a spherical particle rolls down the plane. The rolling sphere thus involves the problem of a moving mesh for which a user defined function or (UDF) is defined and this is imported into fluent for the above said simulation. The angular velocity of the ball is kept constant for each case and that of the slope is varying with each simulation. The media in which the sphere rolls is also changed from time to time for a comparison among the various medias used. ANSYS FLUENT 13 was used for making 3D geometry of the sphere present on the incline. The diameter of the sphere was 3mm. The length of the inclined plane was 200mm. Then fine meshing was done in order to have 15691 nodes for the whole geometry. Then named selection was done for the entire geometry.

b. Simulation

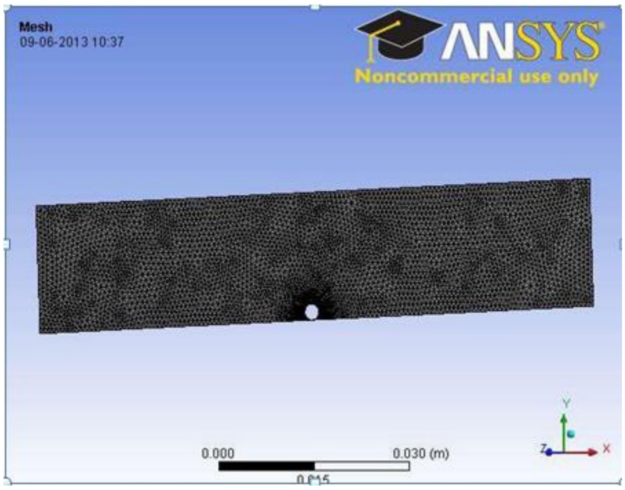

Figure 2. mesh for θ=2°

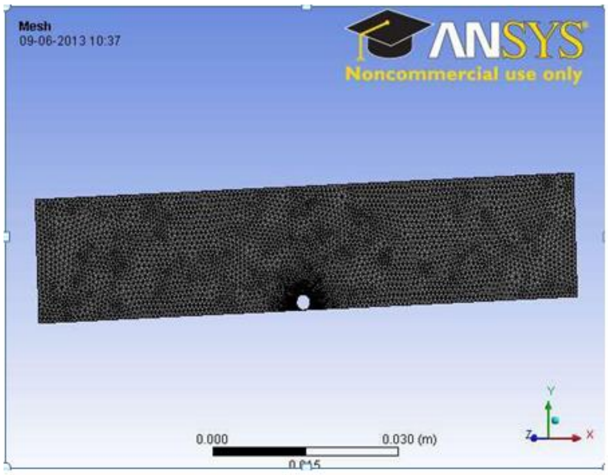

Figure 3. mesh for θ=20°

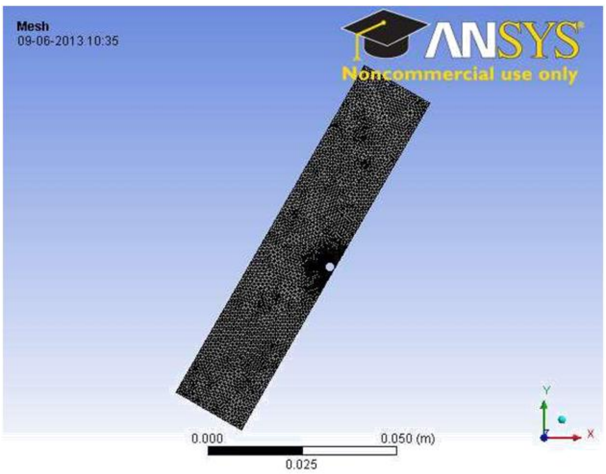

Figure 4. mesh for θ=60°

III. RESULTS AND DISCUSSION

i. Results

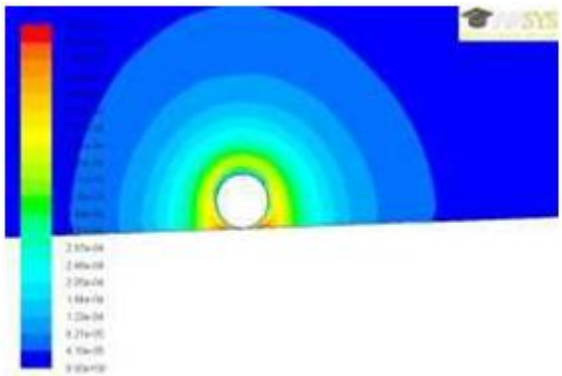

Figure 5. Velocity contour for media water θ=2°, t= 0.15 sec & ω=5 rad/sec

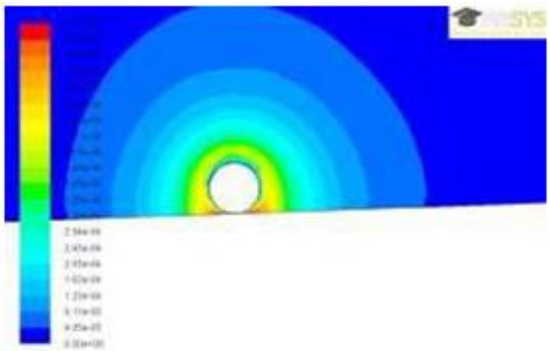

Figure 6. Velocity contour for media water θ=20°, t= 0.15 sec & ω=5 rad/sec

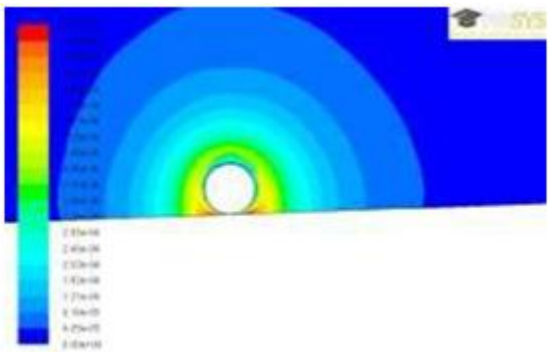

Figure 7. Velocity contour for media water θ=2°, t= 0.3 sec & ω=5 rad/sec

Table 1. Values of velocity for media water , θ= 2° and ω= 5 rad/sec

Media	Angle	Time	Angular velocity	Velocity
water	2°	.15sec	5 rad/sec	.0512 m /sec
water	2°	.2sec	5 rad/sec	.01122 m /sec
water	2°	.3sec	5 rad/sec	.007 m/sec

The velocity of a sphere having a constant angular velocity of 5 rad/sec rolling down an inclined plane of inclination 2° in a water media decreases until it reaches a terminal velocity. Initially it has high velocity because at t=0sec it is given an angular velocity of 5 rad/sec.

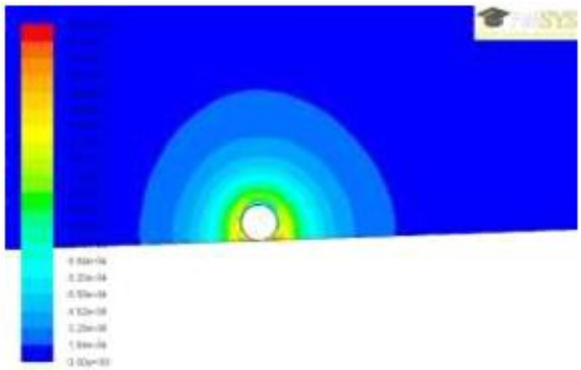

Figure 8. Velocity contour for media water θ=2°, t= 0.15 sec & ω=10 rad/sec

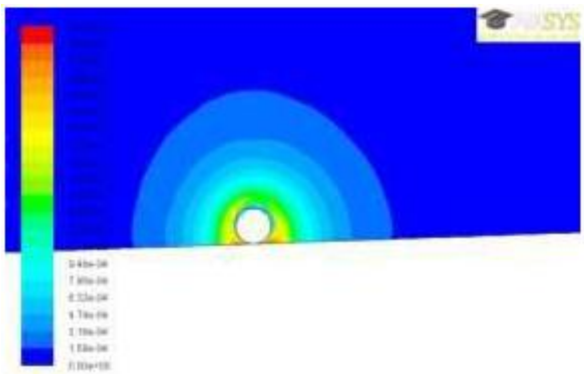

Figure 9. Velocity contour for media water θ=2°, t= 0.2 sec & ω=10 rad/sec

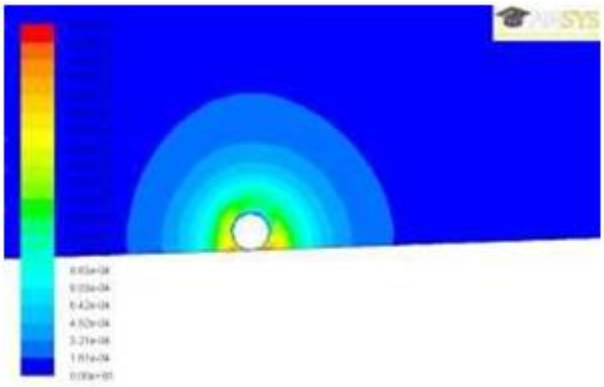

Figure 10. Velocity contour for media water θ=2°, t= 0.3 sec & ω=10 rad/sec

Table 2. Values of velocity for media water , θ= 2° and ω= 10 rad/sec

Media	Angle	Time	Angular Velocity	Velocity
water	2°	.15sec	10 rad/sec	.01526 m/sec
water	2°	.2sec	10 rad/sec	.01129 m/sec
water	2°	.3sec	10 rad/sec	.00738 m/sec

IV.CONCLUSION

Nearer to the solid body surface fluid receives more momentum from the moving solid body and hence the magnitude of velocity was found more nearer to solid surface. As the angle of inclination of the surface increases the velocity change is more pronounced with velocity changes as high as 11.5 times more than that of velocity at lower angles.

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Cite this article as :

Repalla Mohammed Azeem, N. Karthikeyan, L. Balasubramanyam, "Hydrodyamic Study of Newtonian Fluid Flow Over A Sphere Using CFD Models", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 4, pp. 316-320, July-August 2019. Journal URL : http://ijsrset.com/IJSRSET196441