Analysis of drilling fluid flow in the annulus of drill string through computational fluid dynamics

Nishant Joshi¹, Akhilesh Khapre², Amit Keshav³* and Anil Kumar Poonia⁴

¹Research Scholar, Department of Chemical Engineering, NIT Raipur
²Faculty, Department of Chemical Engineering, NIT Raipur
³Associate Professor, Department of Chemical Engineering, NIT Raipur
⁴Associate Professor, Department of Chemical Engineering, NIT Raipur

E-mail: ²akhileshkhapre@gmail.com , ³akeshav.che@nitrr.ac.in

Abstract: During an oil and gas well drilling the drilling fluids are pumped through the drill string to cool and lubricate the drill bit. This also serves the purpose of bringing the rock cutting back to surface and serves various other purposes also like pressure control and maintain well bore stability. As the well is drilled the casing are lowered from the well from caving in. This results in a situation where there is an annular flow of drilling fluid where the inner pipe is rotating while the outer pipe is stationary. The understanding of fluid dynamics of such situation is extremely important and detailed investigations are required. Though experimental investigation will reflect the actual behavior but with the advancement is the numerical techniques such experimentation can be avoided with the application of computational fluid dynamics. Therefore, the present study employs the homogeneous model to simulate a single-phase fluid flow and predict pressure loss variation in eccentric vertical annuli as a function of varying drilling parameters: fluid velocity, inner pipe rotation speed

1.Introduction

Hydrocarbons such as oil and gas are produced by drilling. Modern day drilling rotary drilling practices in which the pipe with a drilling bit rotates and penetrates the earth crust. In order to provide cooling and lubrication of bit, drilling fluid is pumped down inside the pipe through mud pumps. The drilling fluid lifts the rock cuttings as it flows through the annulus and is very important in balancing the pressure so that safe drilling can be carried out.[1] As the well is drilled the casings are lowered in order to prevent the well from caving in. This arrangement results in an annular flow of the drilling fluid between two concentric pipes with the inner pipe rotating at different angular velocity.[2] There are different types of drilling muids used in the industry such as water based and oil-based drilling muids depending on whether the continuous phase is water or oil. The fluid flow is affected by the rheology of the drilling fluid, eccentricity and rotational speed of the inner pipe.

Researchers working in various domains have worked in this domain and evaluated such problem experimentally, analytically and numerically. The drilling fluid generally behaves as non-Newtonian as its fluid viscosity changes with applied shear. [3]Different
model such as Power law model, Herschel-Buckley and Bingham Plastic have been used to describe the behavior of non-Newtonian fluid.[3]

First significant study was carried out by Ahmed(2010) that evaluated the relationship between pressure loss and drill string rotation speed which depended on the wellbore geometry and flow regime.[4] The influence of the weight of mud and annular diameter ratio in inclined wells was studied by Becker.

Numerous and diverse study in the field of computational fluid dynamics to calculate the various properties and parameters which influence the flow of transporting fluid in the rotational drilling have been studied.[5–8] Recent research shows that some oil-based mud follows Casson rheological model. [3,9,10] So far, the accessibility of this scientific literature the numerical studies with rheology represented by Casson model is still not available.

Therefore, the presented work aims at the study of pressure loss variation of fluid in drilling pipe due change in the rotational speed and the inlet fluid velocity.

2. Computational Fluid Dynamics Methodology

In the present work commercial software simFlow4.0 was used that works on Finite volume approach. In the finite volume method, the computational geometry is divided into infinitely small finite volume for which the governing equations are solved. The geometry consisted of two concentric pipes with flow simulated in the annular region. The inner diameter of the outer pipe was 0.0889m while the outer diameter of the inner pipe was 0.127m. The geometry was fine meshed with 150000 cells.

![Computational geometry used in the present work](image)

The dimensions of the geometry, annular velocity and angular velocity have been taken so as to represent the actual conditions encountered during drilling.

| Parameter               | Min  | Max  |
|-------------------------|------|------|
| Eccentricity            | 0    | 0.98 |
| Velocity(m/s)           | 0.26 | 1.57 |
| Angular Velocity (RPM)  | 50   | 200  |

3. Governing Equations

Mass Conservation Equation

\[
\frac{\partial p}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0
\]  

(1)

For incompressible flow the equation (1) can be written as a simplified manner

\[
\nabla \cdot \mathbf{u} = 0
\]  

(2)

Momentum Conservation Equation
Conservation form of momentum equation by the application of Newton’s second law of motion to a fixed fluid element is described by three scalar equations X, Y and Z directions for viscous flows it is called Navier-Stokes equation. Conservation form is described as:

\[
\rho \left[ \frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u} \right] = -\nabla p + \nabla \cdot \tau + \rho \vec{f} \tag{3}
\]

RANS k-e turbulent model was utilized and the Casson model was chosen for viscosity variation in the Navier-Stokes equation as given by the equation (4)

\[
v = \left[ \sqrt{\frac{\tau}{\gamma} + \sqrt{m}} \right]^{0.5} \tag{4}
\]

A steady state simulation was carried out. Upwind scheme was used for solving the convective term. Linear interpolation method was utilized. SIMPLE scheme for pressure velocity coupling. Velocity at the inlet and pressure at the outlet was defined. No slip condition was imposed at the outer wall of the annulus whereas the inner wall was given rotational velocity. The residual convergence criterion was set at 10^{-4}

4. Results and Discussions

In the study the inlet velocity was chosen between 0.26 m/s to 1.57 m/s which correspond to mud flow in the range of 50-300 US GPM. The angular velocity was taken in the range of 50-200 RPM which is usually encountered while drilling. Eccentricity was varied between 0 -1 as the drill pipe position continuously changes while drilling. The Casson model parameters have been obtained from the literature.[3] Pressure loss was observed for unit length of pipe and the values are presented in the form of graphs.

4.1 Pressure Loss vs Velocity

The graph between the inlet velocity and the pressure drop (at constant angular velocity of inner pipe at 50RPM) is shown in Fig1. It can be seen from the graph as the inlet velocity increases the pressure drop increases.

![Figure 2. Variation of pressure loss vs inlet velocity of annulus](image)

4.2 Pressure Loss vs Angular Velocity
As the angular velocity was increased from 50 RPM to 200 RPM the pressure loss increases when the inlet velocity at the annulus was kept at 0.26 m/s.

![Graph showing pressure loss vs angular velocity](image1)

**Figure 3.** Variation of pressure loss vs angular velocity of inner pipe

### 4.3 Pressure Loss vs Eccentricity

Figure 4 represent the variation in the pressure drop as the eccentricity is varied from 0 to 0.98. The inlet velocity is maintained at 0.26 m/s and angular velocity is maintained at 50 RPM. It can be observed from the graph that pressure loss is higher for fully eccentric pipe. The pressure loss is least when the inner pipe is concentric with the outer pipe.

The velocity contours in the three cases with eccentricity 0, 0.5 and 0.98 are presented in Figure 5(a), 5(b) and 5(c) respectively.

![Graph showing pressure drop vs eccentricity](image2)

**Figure 4.** Variation of pressure loss vs eccentricity
5. Conclusion

Numerical simulation has been carried to estimate the effect of angular velocity, inlet velocity and eccentricity on the pressure loss in the annulus of pipe while drilling mud is pumped. Casson model representing the rheology of the drilling mud is utilized. The results indicate that the pressure loss is in direct relation with the inlet velocity and the rotational velocity. The pressure loss is lower in concentric pipe than the case where the pipe is fully eccentric.

6. References

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