DRILL PIPE ROTATION EFFECTS ON NON-NEWTONIAN FLUIDS FLOW IN ECCENTRIC ANNULI

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ABSTRACT – The horizontal wells drilling process is characterized by the fluid flow through an annulus, usually, eccentric. The annulus geometry is modified by the deposition of cuttings on the bottom of the annular section and by eccentricity, which change the flow patterns and affect the cuttings removal process. The drill pipe rotation is one of most important operational parameter of the cutting removal process, helping the gravels ressuspension, optimizing and improving the wellbore cleaning process. Using the CFD technique, the present study analyzed the laminar fluid flow of non-Newtonian fluids through an annular space with inner cylinder rotation, in order to evaluate the drill pipe rotation effects on the performance of the cleaning process. Five rotational speed values were evaluated. The study shows that the increase of drill pipe rotation causes an increase on the axial and tangential velocity at the narrowest gap, which have positive effects on the cuttings removal process.

Keywords: drill pipe rotation, eccentric annuli, CFD.

INTRODUCTION

With the discovery of new oil fields, the horizontal drilling process became an attractive process, due to the increase of the contact area of the wellbore with the reservoir, causing an improvement on production and process efficiency. The drilling process is characterized by a fluid flow through an annulus and, for horizontal wells, due to gravitational effects, the drill string is usually displaced, generating an eccentric configuration. Besides, the accumulation of cuttings on the bottom of the annular section and the drill string eccentricity, changes the flow pattern and affects the wellbore cleaning process. Cuttings removal process is an important issue in horizontal wells drilling, and it is affected by many parameters, including the drill pipe rotation, which has a great importance in the process (Caenn and Chillingar, 1996; Loureiro and Siqueira, 2006a; Tardy and Bittleston, 2015; Vieira Neto et al., 2014; Pereira et al., 2007).

In a combined numerical study, using CFD and the Discret Element Method (DEM), Akhshik et al. (2015) analysed the drill pipe rotation effects on the behavior of cuttings transport, the concentration of particles is significantly reduced with the presence of drill pipe rotation. The authors also points out that this parameter improves the wellbore cleaning, mainly to low flow rates.

In an experimental study, Loureiro and Siqueira (2006) have investigated the sediment cuttings bed height in obstructed annular spaces. They showed that, for the analyzed bed heights, the drill pipe rotation causes a displacement of sediments allowing the transport of the particles by the axial flow, which improve the efficiency of hole-cleaning process.

In an experimental study, Nouri and Whitelaw (1997) investigated the fluid flow of Newtonian and non-Newtonian fluids in an eccentric annulus with inner cylinder rotation and they concluded that, for both fluids, the rotation had similar effects, with more uniform distribution of axial flow and the maximum tangential velocities in many parameters, including drill pipe rotation, which has a great importance in the process.
the narrowest gap.

Sun et al. (2014), using the CFD technique, studied the effects of drill pipe rotation on cuttings transport in complex structure wells and they concluded that the drill string rotation causes a significant increase in the tangential velocity of the drilling fluid, which generates a drag force in the drill pipe tangential direction, inhibiting the cuttings bed formation.

Vieira Neto et al. (2014), studied numerically and experimentally the effects of inner cylinder rotation on the fluid dynamics of non-Newtonian fluids in concentric and eccentric annuli, concluding that the introduction of the inner cylinder rotation increased the pressure drop along the axial direction and the axial flow in the narrowest gap, which is beneficial to the cleaning process, once reduces the flow stagnation in this region.

Wang et al. (2009), analysed the effects of drill pipe rotation on borehole cleaning for horizontal wells using the CFD technique applied to a multiphase study (solid-liquid). The authors concluded that the drill pipe rotation reduces the solids concentration in the annulus, besides that, it increases the solid phase migration to the fluid flow, promoting the wellbore cleaning and improving the process efficiency.

It is fact that the cuttings removal has a great importance on drilling process. An inefficient cuttings transport interferes in the drilling velocity, rising the time and the cost of the operation. Under these circumstances, studies are carried out in order to understand the influence of each parameter of the cuttings removal process, aiming to optimize and improve the wellbore cleaning efficiency. This study uses computational fluid dynamics (CFD) in order to evaluate the drill pipe rotation effects on the performance of the cleaning process. Axial and tangential velocity, pressure drop and effective viscosity will be analysed.

**BASIC EQUATIONS**

The equations governing the flow for the cases analyzed in this paper are:

**Continuity equation:**

\[ \nabla \cdot \vec{V} = 0 \] (1)

**Navier-Stokes equation:**

\[ \rho \frac{D\vec{V}}{Dt} = -\nabla P + \rho g + \mu (\nabla^2 \vec{V}) \] (2)

In the above equations, \( V \) is velocity, \( \rho \) is specific mass, \( P \) is pressure, \( g \) is gravity and \( \mu \) is the effective viscosity of the fluid.

**Cross model**

The Cross viscosity equation is a four parameters model used to represent shear-thinning fluids.

This model is represented, according Chhabra and Richardson (2008), by Equation (3).

\[ \frac{\mu - \mu_0}{\mu_0 - \mu_\infty} = \frac{1}{1 + k(y_{xy})^n} \] (3)

In the above equation, the power index \( n \) is smaller than one and together with the consistency index \( k \) are two fitting parameters, while \( \mu_0 \) and \( \mu_\infty \) are the limiting values of effective viscosity at low and high shear stress, respectively, and \( y_{xy} \) is the shear strain (s⁻¹).

**METHODOLOGY**

This study uses Computational Fluid Dynamics (CFD), software Ansys® CFX 16.0 preview 4, in order to evaluate the drill pipe rotation effects on fully developed laminar fluid flow of non-Newtonian fluid through an annulus. The geometry was based on the study of Escudier et al. (2002) and consists of two cylinders. The external cylinder, with 0.0502 m radius (\( r_e \)), is static and the inner cylinder, with 0.0254 m radius (\( r_i \)), rotates with a constant speed. Both cylinders were 5.775 m long.

Eccentricity (\( \varepsilon \)) is a dimensionless parameter, which is equal to zero for a concentric annulus and one for a fully eccentric case, it is defined by Equation (4), where "e" is the distance between the centers of the inner and outer cylinders and \( \delta \) is the difference of the outer radius and the inner radius.

The dimensionless distance from inner cylinder (\( \sigma \)), in the region between the inner cylinder and the outer wall, is defined by Equation (5), where "y" is the radial distance measured from inner cylinder and "s" is the gap width. Figure 1 shows the Schematic representation of the geometry studied.

\[ \varepsilon = \frac{e}{\delta} \] (4)

\[ \sigma = \frac{y}{s} \] (5)

The drilling fluid used, based on Escudier et al. (2002) study, is an aqueous solution of 0.1% xanthan-gum and 0.1% carboxymethylcellulose (CMC) and the non-Newtonian characteristics of the fluid is represented by the rheological Cross model. Table 1 shows the drilling fluid parameters. Five drill pipe rotation values were evaluated, varying from \( \omega = 0 \) s⁻¹ (no rotation case) to \( \omega = 20.96 \) s⁻¹. A structured mesh was used for the simulations, the mesh independent condition was verified for the critical case (\( \omega = 20.96 \) s⁻¹). To control the
number of elements on the azimuthal direction, the minimum and maximum face sizes were set to 0.001 m, the number of divisions was 40 in the radial direction and 256 in the axial direction.

Table 1 - Rheological fluid parameters.

<table>
<thead>
<tr>
<th>Cross parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_0 ) (Pa.s)</td>
<td>0.262</td>
</tr>
<tr>
<td>( \mu_\infty ) (Pa.s)</td>
<td>0.00144</td>
</tr>
<tr>
<td>K (s(^n))</td>
<td>2.414</td>
</tr>
<tr>
<td>n</td>
<td>0.504</td>
</tr>
</tbody>
</table>

Figure 1. Schematic representation of the geometric parameters.

Figure 2. Computational mesh – 40x256 divisions.

The simulations were carried out in the steady state regime, the gravitational effects were neglected and the convergence criteria used was \( 1 \times 10^{-4} \). The boundary conditions adopted were: axial velocity \( U = 0.268 \) m/s at the entrance, inner rotation speed of 5.24 s\(^{-1}\), and outlet opening condition with relative pressure set to 0 Pa.

RESULTS

In this section we present the results of the simulations. The obtained results will be presented in two parts. At first, the numerical model validation is shown. The experimental data of Escudier et al. (2002) were used to validate the model. In the second part, the effects of eccentricity on the dimensionless axial velocity are shown, followed by the effects on the dimensionless tangential velocity profiles, pressure drop and effective viscosity.

Validation of CFD Computational Model

In this section, the CFD model is validated using the experimental data of Escudier et al. (2002). According to Figure 3 the dimensionless axial velocity simulated in this work showed a good agreement with the work of Escudier et al. (2002). The axial velocity distortion due to eccentricity observed by Escudier et al. (2002) was also observed by the numerical approach, a flat profile at the wider gap due to the shear thinning characteristics of the fluid was observed too.

Figure 3. Comparison between the present numerical study and the experimental data of Escudier et al. (2002).
The relative error for the maximum velocity at the top gap was 3% and at the bottom gap 17%. A good agreement was also observed for the dimensionless tangential velocity, with the recirculation zone reported by Escudier et al. (2002) in almost whole top gap (Sector B) also been observed in the present study. The relative error in this Sector (top gap) was 3%. Therefore, the numerical model is validated in order to carry the study in the eccentric annulus evaluated in this work.

Drill Pipe Rotation Effects

In this section will be present the results of the simulations. It is observed in Figure 4 the effects of drill pipe rotation on the axial velocity profiles (\(u\)).

![Figure 4](image)

Figure 4. Drill pipe rotation effects on dimensionless axial velocity profiles at the bottom gap of annular section.

According to the profiles, it is possible to see that with the introduction of inner cylinder rotation there is an increase of axial flow at the bottom of the annular, where, for the case without rotation (\(\omega = 0 \text{ s}^{-1}\)), the dimensionless axial velocity was equal to \(\bar{u} = 0.245\), and to \(\omega = 20.96 \text{ s}^{-1}\) equal to \(\bar{u} = 1.203\) (Increase of almost 80%). Similar results were reported by Vieira Neto et al. (2014). This increase would be beneficial to the wellbore cleaning process because the flow stagnation is reduced, avoiding the deposition of cuttings and improving its transport.

Figure 5 shows the effect described above, a displacement of the top speed zone, a reduction of the fluid flow at the top gap and a more uniform axial velocity distribution on the whole annular, with the increase of drill pipe rotation. This effects were observed by Pereira et al. (2007) and Vieira Neto et al. (2014). A more uniform velocity distribution helps to keep the cuttings fully suspended in the fluid, avoiding the formation of sediment bed at the bottom gap, improving the performance of hole cleaning process.

![Figure 5](image)

Figure 5. Drill pipe rotation effects on dimensionless axial velocity contours.
In Figure 6 are exposed the effects of drill string rotation on the tangential velocity profiles (v) at the bottom gap of annular. The increase in the rotation speed lead to an increase on the tangential velocity in this sector, which helps the cleaning process, because the cutting are tangentially dragged by the drilling fluid and higher rotation speeds can provide more energy to the cuttings suspension. The result found is in agreement with the literature, similar results were found by Sun et al. (2014), Vieira Neto et al. (2014), Pereira et al. (2007) and Nouri and Whitelaw (1997).

In Figure 7 the rotation effects on the pressure profiles along the drill string are presented. It is possible to note that occurs an increase of approximately 13% on pressure drop as the rotation speed increase, what is in accordance with Vieira Neto et al. (2014).

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**CONCLUSIONS**

This study evaluated the effects of drill pipe rotation on the axial and tangential velocity profiles and on the axial velocity contours in the annular space. The results of the simulations shows that the drill pipe rotation speed affects the flow pattern in the annular space and the pressure drop.

The increase of drill pipe rotation lead to an increase of axial and tangential velocities at the bottom gap of annular section, which is positive to the wellbore cleaning process. For the pressure drop was observed that the rotation speed increase causes an increase on pressure drop along the axial direction.

As a suggestion for future work it is observed the necessity of studying other parameters involved in drilling process, like eccentricity and inclination of the column.

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