INFLUENCE OF GEOMETRIC AND OPERATIONAL PARAMETERS ON HORIZONTAL WELLS CLEANING PROCESS

Hóliver Zambon Zanete, holiverzambon@gmail.com[1]
Renato do Nascimento Siqueira, renatons@ifes.edu.br[1]

Instituto Federal do Espírito Santo, Rodovia BR 101 Norte – Km 58 –Litorâneo, São Mateus, ES, 29932-540, Brazil.

Abstract. *The well drilling process represents a significant part of the total operational cost of an oil field. Aiming to improve the extraction efficiency, the horizontal drilling technique has been widely used because it allows an increase of the contact area between the wellbore and the reservoir. Despite the benefits, some problems arouse from the use of this technique. The main problems are the eccentricity of the column, due to the gravitational effect, and the sedimentation of the cuttings, which forms a solid bed, impairing the transport of the cuttings from the well. Among the parameters that can affect the well drilling process performance are: rheology of the drilling fluid, axial-flow rate, inner cylinder rotation, eccentricity and diameters ratio. This study uses Computational Fluid Dynamics (CFD) to evaluate the influence of these geometric and operational parameters on the flow of a non-Newtonian fluid characterized by Herschel-Bulkley rheologic model. The geometry consists of an inner cylinder of radius* d_i *= 50.8 mm and the outer cylinder diameter (*d_o*) varies according to the diameter ratio (k) considered. For the present study the k value varied from 0.5 to 0.9; the eccentricity (*ε*) ranged from 0 (fully concentric) to 0.8; the inner cylinder rotation (*ω*) varied from 0 to 400 rpm; and the Reynolds number (Re) varied from 200 to 1000, assuring the condition of laminar flow. The drilling fluid has a specific mass* ρ *= 1000 kg/m, yield stress* τ_0 *= 17.81 Pa, consistency index K = 0.26 Pa.s and behavior index n = 0.74. The data show that contrary to the rotational speed, the majority of parameters have influence on the pressure drop along the flow and a mathematical relationship was proposed for determining the influence of the geometric and operational parameters on pressure drop, contributing to the definition of a well drilling strategy.*

Keywords*: Annular flow, CFD, Non-Newtonian fluid, Horizonal wells.*

1. INTRODUCTION

The optimization of processes in the oil industry has as main objective the reduction of costs associated with the exploration and production, ensuring the viability and competitiveness of the activity.

During the well drilling process, a fluid is injected into the interior of the drill string and returns to the surface through the annular space formed between the drill string and the outer walls, transporting the cuttings generated by the fragmentation of the reservoir rock.

Seeking higher efficiencies and to reduce costs associated with the oil extraction activity, the horizontal drilling technique has been widely used. In addition to increase the contact area between the wellbore and the reservoir, this technique enables drilling reservoirs where the drilling point on the surface is not immediately above the reservoir but, despite the benefits, some problems are generated from the application of this technique.

In actual drilling conditions, the sedimentation of cuttings is one of the problems encountered. It tends to form a bed of solid particles in the lower region of the well, which tends to accumulate with the advance of the drilling process and may lead to blockage of the drill string and loss of the well.

Another major factor that changes the geometry of the annular space is the displacement of the drill string to the lower region of the well, due to gravitational effects, which generates an eccentricity in the annular space. The effect of eccentricity on the process performance has already been evaluated by several studies in the literature.

As stated before, during the drilling process, the cuttings generated from the fragmentation of the reservoir rock must be removed from the well and taken to the surface. Although the drilling fluid has several functions, the main function is the transport of the cuttings. Drilling fluids are complex mixtures of solids, liquids, chemicals and even gases, giving them non-Newtonian fluids properties (Thomas, 2001). To have a better performance, a fluid must have sufficient viscosity to promote the drag of solid particles and, at the same time, it should promote the lowest possible pressure drop, aiming to reduce energy consumption and control the downhole pressure.

Understanding the pressure loss behavior during drilling process allows engineers to correctly dimension the pumping units, besides the correct control of downhole pressure.

Several factors may influence the cuttings transport efficiency. According GhasemiKafrudi and Hashemabadi (2015), the main factors are: drillpipe rotational speed and eccentricity, inner and outer cylinder diameters, penetration rate, axial velocity, flow regime and rheological properties. Authors such as Gabriel and Siqueira (2015), Loureiro et al. (2006), Lídio and Siqueira (2015), Costa et al. (2013), Escudier et al. (2002) and Tardy and Bittleston (2015) also investigated the influence of these geometric and operational parameters on the cleaning process.

Escudier et al. (2000) noticed the strong influence of the column rotational speed on the axial velocity distribution in an eccentric annular. Similarly, Loureiro et al. (2006) concluded that the rotation of the column affect the suspension of the cuttings when a large thickness sedimentation bed is present.

Loreiro and Siqueira (2006) found that the minimal shear stress to start an erosion process in a sedimented bed depends on the flow rate and it is directly related to the average particle size.

Sun et al. (2014) evaluated the influence of the slope and column speed for different flow rates and found that the effect of flow rate on cuttings concentration in the bottom is more pronounced for higher rotational speeds.

Pereira et al. (2007) observed an increase in the pressure drop in an eccentric annulus as the rotation of the inner cylinder increases. The authors also observed the presence of preferential flow zones and flow stagnation zones.

Zanete and Siqueira (2015) showed the influence of the axial flow rate of a non-Newtonian fluid described by the Power-law rheological model in an eccentric annular space and concluded that higher flow rates provide axial displacement of the regions of increased speed towards the lower annular space of an eccentric well.

Pereira (2006) proposed two correlations to predict the pressure drop in the flow of a non-Newtonian fluid in annular spaces as a function of flow rate, drill pipe rotation and polymer concentration to concentric and eccentric annuli. According to the author, the polymer concentration has the greater influence on the pressure drop, followed by the flow rate and rotation. Moreover, the increased concentration and increased flow rate lead to an increase in the pressure drop while increasing the rotation reduced pressure drop.

Bicalho et al. (2015) evaluated the influence of drillpipe eccentricity and rotation, flow rate and fluid behavior index on the pressure drop in an annular flow. Using a Composite Central Planning (CCP), the authors performed 25 flow simulations and proposed a correlation to the pressure drop. The authors noticed that the eccentricity of the column showed no significant influence on the pressure drop. The flow rate and the fluid behavior index positively influenced the pressure drop, while increasing the rotation had the opposite effect.

The well drilling is carried out in several stages. In the initial stages larger diameter drills are used and, as it approaches the reservoir, the diameter of the drill is reduced, causing the geometry of the annular space to vary during drilling. Although drill size variations, the dimensions of the column are the same throughout the well, which causes the internal diameter of the annular to remain constant while the outer diameter varies according to the drilling stage. Therefore, a very important variable arises in the process, which is known as diameter ratio.

This work evaluates the influence of geometric and operational parameters like Reynolds number, drillpipe rotational speed, column eccentricity and diameter ratio on the pressure drop and proposes a relationship that can accurately predict the pressure drop in the flow of a non-Newtonian fluid in an annular space.

2. BASIC EQUATIONS

2.1. Governing equations

The equations governing the flow for the cases analyzed in this paper are continuity and Navier-Stokes equations, described by Eq. (1) and (2), respectively.

$$\nabla.\vec{V} = 0 \tag{1}$$

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

In the above equations, V is velocity, ρ is specific mass, P is pressure, g is gravity and μ is the effective viscosity of the fluid, determined by a chosen rheological model (Pereira et al., 2006).

2.2. Rheological model

The rheological model selected to represent the viscosity of the non-Newtonian fluid was the Herschel-Bulkley, which is given by Eq. (3).

$$\tau = \tau_0 + K\dot{\gamma}_{xy}{}^n \text{ para } \tau > \tau_0 \tag{3}$$

In the above equation, τ is shear stress, τ_0 is yield stress, $\dot{\gamma}_{xy}$ is the deformation rate, K is the consistency index and n is the fluid behavior index.

2.3. Dimensionless parameters

For determining the flow regime the critical Reynolds number for laminar flow was used. According to Pereira (2006), the critical Reynolds number for the flow in an annular space is in the range 2000-2300.

Madlener et al. (2009) relationship, shown in Eq. (4), represents the generalized Reynolds number for non-Newtonian fluids characterized by rheological Herschel-Bulkley model.

$$Re = \frac{\rho \bar{u}^{2-n} {D_h}^n}{(\tau_0/8)(D_h/\bar{u})^n + K[(3m+1)/(4m)]^n 8^{n-1}} \tag{4}$$

In the above equation, the term *m* represents the local shear stress gradient and is defined by Eq. (5). Eq. (6) is used to determine the hydraulic diameterD_h.

$$m = \frac{nK(8\bar{u}/D_h)^n}{(\tau_0 + K(8\bar{u}/D_h)^n} \tag{5}$$

$$D_h = D_o - D_i \tag{6}$$

D_o is the external diameter and D_i is the internal diameter.

The eccentricity is defined by the displacement of the center of the inner cylinder relative to the center of the outer cylinder and is given by Eq. (7).

$$\boldsymbol{\varepsilon} = \frac{\boldsymbol{2e}}{\boldsymbol{D_o - D_i}} \tag{7}$$

Where "$\boldsymbol{e}$" represents the displacement of the center of rotation of the inner cylinder relative to the center line of the outer cylinder as shown in Fig. 1.

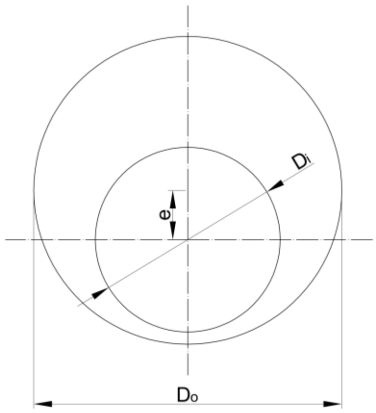


Figure 1. – Schematic representation of the geometry evaluated in this study.

The diameter ratio is the ratio between the diameter of the inner cylinder and the diameter of the outer cylinder and is given by Eq. (8).

$$\boldsymbol{k} = \frac{\boldsymbol{D_i}}{\boldsymbol{D_o}} \tag{8}$$

3. METODOLOGY

Seeking to represent real conditions observed during the well drilling, the variables diameter ratio (*k*), eccentricity (ε) column rotational speed (ω) and Reynolds number (*Re*) were selected to analyze their influence on the pressure drop.

The flow problem was investigated using a simplification of an annular space between the well and the drill string. The geometry consists of an annular space where the inner cylinder diameter D_i = 0.0508 m and the outer cylinder diameter varies depending on the diameters ratio considered. The length of the pipe is 2.5 m. The geometry eccentricity ranged from 0 to 0.8. The rotation of the column varied from 0 to 400 rpm and the Reynolds number from 200 to 1000, maintaining the laminar flow condition.

The rheological data were selected following the work Pereira (2013) for a standard fluid used in drilling activities. The Herschel-Bulkley model is preferred over other rheological models such as Power-law or Bingham plastic because it can adjust the flow behavior more precisely when it has adequate experimental data (Hamed and Belhadri, 2009). The fluid used in this work has yield stress $\tau_0 = 17.81$ Pa, consistency index $K = 0.26$ Pa.s and behavior index $n = 0.74$.

The study was conducted using Computational Fluid Dynamics (CFD) with the software Ansys® CFX - Version 16.0. A structured mesh was used in the simulations. The mesh structure consists of 90 divisions in the radial direction, 108 in the axial direction and 220 in the azimuthal direction. A grid indepence test was performed to verify the independence of the results obtained in relation to the size of the mesh elements. The convergence criterion used was residual target equal to 10^{-4}. We evaluated five levels for each parameter analyzed, totaling 625 simulations. The planning of experiments is shown in Tab. 1.

Table 1. Parameters and test levels.

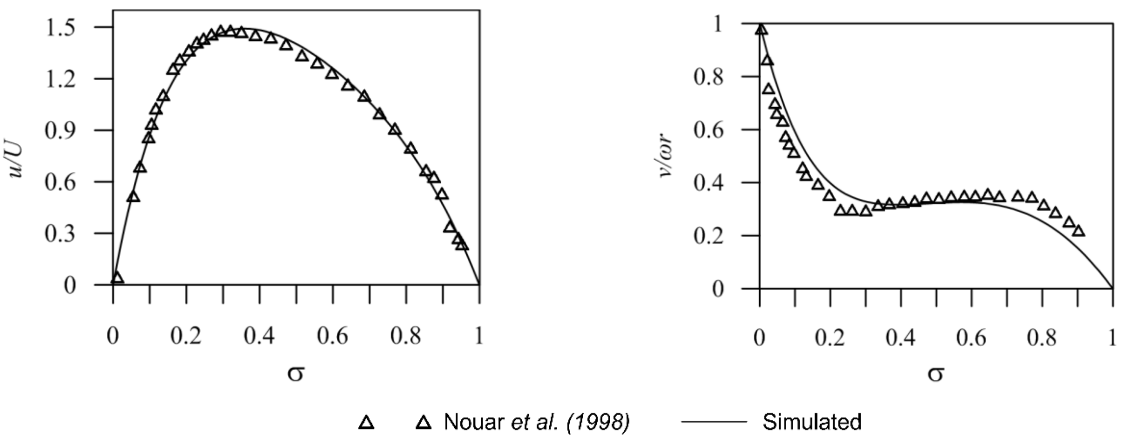
Parameters	k	ε	ω (rpm)	Re
Levels	0.5	0.0	0	200
	0.6	0.2	100	400
	0.7	0.4	200	600
	0.8	0.6	300	800
	0.9	0.8	400	1000

A non-linear multiple regression scheme was used to predict the influence of these variables on pressure drop. The significance of the model was evaluated based on an analysis of residues for the fitted model.

4. RESULTS

4.1 Model validation

We run a set of simulations following the work of Nouar et al. (1998) for validating the CFD model. Axial and tangential velocity profiles for two different cases were compared. The numerical data obtained through the simulations showed good agreement with the experimental data Nouar et al. (1998), ensuring the representation of the model. The results are shown in Fig. 2.



(a) U = 0,0728 and ω = 268,18 rpm

(b) U = 0,0728 and ω = 26,5 rpm

Figure 2. Non-dimensional axial and tangential velocity profiles.

4.2 Velocity contours

Figure 3 shows the variation of the non-dimensional velocity contours due to the changes in the parameters evaluated. A base case with lower values for all parameters was chosen and then, each parameter was changed at a time, keeping the other parameters contant, to compare with the reference case. The standard case for comparison has diameter ratio k = 0.5, eccentricity ε = 0, rotation ω = 0 rpm and Reynolds number Re = 200.

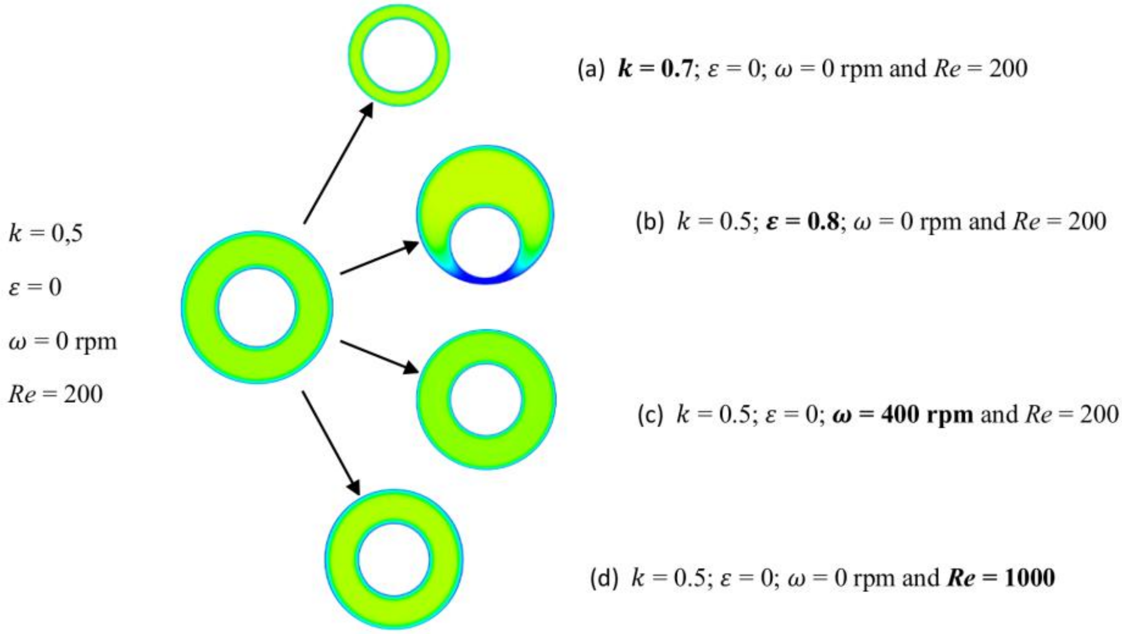


Figure 3. Variation of velocity contours due to changes on geometric and operational parameters.

In the first case (Fig. 3a), the eccentricity, rotation and Reynolds number values were maintained and the influence of the increase in diameter ratio on the non-dimensional axial velocity contours was examined. An increase in the axial velocity in the central region of the annular space was observed with the increase in the diameter ratio. A brief analysis of the pressure data demonstrated that increasing the diameters ratio significantly increases the pressure drop. This behavior can be explained by the decrease of free flow area that causes a restriction to fluid flow and, consequently, displaces the velocity profile to the central region of the annular space and increases and pressure loss.

In the second case (Fig. 3b), the influence of the eccentricity on of axial velocity contours was analized. It is possible to observe a sharp reduction in axial velocity in the lower annulus region. The data showed that for cases without rotation of the inner cylinder a stagnant zone is firmed in this sector for all Reynolds numbers analyzed. This behavior is due to restrictions imposed on the flow in this sector, which drives the fluid to the largest annular space region.

For the increase of Reynolds, it was possible to observe a slight increase in the maximum velocity in the central region of the flow. This increase in the maximum flow velocity may be beneficial to the cuttings transport, since the higher velocities provide higher drag force on the solid particles, allowing a more efficient cuttings removal.

To the increase of inner cylinder rotation, it was not found significant changes in the velocity contours, especially for low eccentricity values. As the eccentricity increases, the rotation of the inner shaft tends to have the greater effect on the velocity profiles, particularly in the region of lower annular space, where the effect of the tangential fluid velocity on the entrainment of the cuttings on the main flow is more dominant. The tangential fluid velocity causes a better suspension of the cuttings retained in the lower region of the well, which facilitates its transport to the surface.

4.3 Pressure drop analysis

A prior analysis of each variable individual behavior on the pressure drop was performed to predict the relationship between the dependent variable (ΔP) and the independent variables k, ε, ω, and Re.

A first analysis showed that the rotation of the inner cylinder has little influence on the pressure drop for all cases studied here. Although authors as Pereira et al. (2007) have observed significant influence of the inner cylinder rotation on the pressure drop, the lack of dependence presented in this work reinforces the idea that the system response depends on a number of other factors, and this statement can only be valid for the conditions discussed here, mainly the fluid rheology. Therefore, the variable inner cylinder rotation was removed from the regression analysis to simplify the problem formulation and analysis.

The second stage was to analyze the relationship between the other independent variables and the system response. A linear relationship was observed for eccentricity and Reynolds number variables with the response variable ΔP and a non-linear relationship between the variable diameter ratio and the system response. Thus, the estimate of the correlation parameters would become a laborious task and it would be difficulty to propose a regression model that fit the data.

To allow a better analysis of the data, the analysis procedure was divided into two stages. Using the methodology recommended by Devore (2006), where the author proposes to use categorical variables to separate the data according to a category. Since the variable *k* has a nonlinear relationship with the response variable, we chose to use it as a categorical variable in the analysis. The data were separated according to the value of *k*, forming five sets of 125 simulations for each value of *k*.

A multiple linear regression procedure was performed to determine the influence of the variables ε and *Re* on the pressure drop response. A linear forecasting model has been proposed which is a mathematical function of the ε values and *Re*, according to Eq. (8).

$$\Delta P = a_0 + a_1 \varepsilon + a_2 Re \tag{8}$$

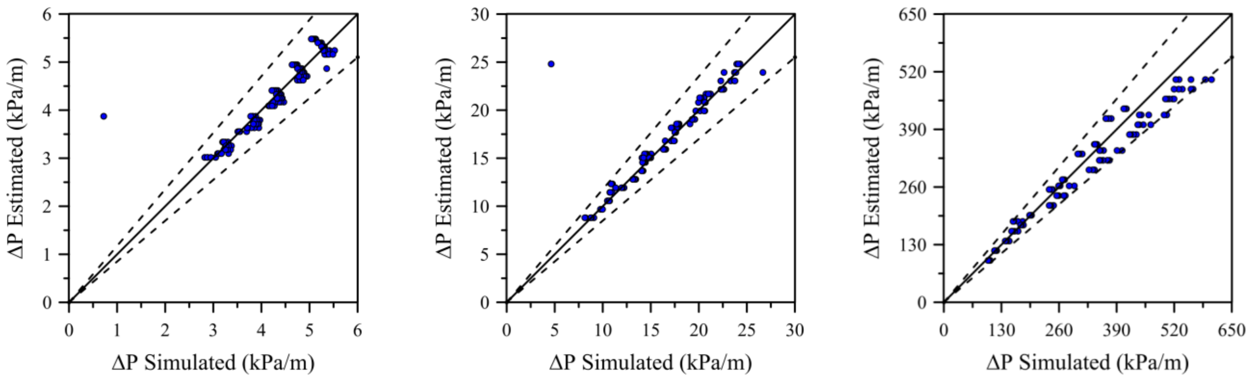
Where a_i are the parameters of the regression, representing the influence of each independent variable on the response.

Table 2 shows the results obtained for the multiple regression of pressure drop values for each value of *k*.

Table 2. Multiple regression parameters.

Categorical variables	a_0	a_1	a_2
$k = 0.5$	2.8	-0.4	0.00268
$k = 0.6$	5	-1.4	0.0056
$k = 0.7$	9.2	-4.4	0.0156
$k = 0.8$	18.8	-14	0.056
$k = 0.9$	102.4	-110	0.4

Figure 4 shows the comparison charts for predicted values of ΔP versus simulated values for three levels of the categorical variables. The residues were calculated for all the fittings as the difference between the simulated value and the estimated value with the proposed prediction model. The largest errors were found for large diameters ratios, where the pressure drop value proved to be quite high. The forecasting models, distributed by categorical variable (*k*), showed maximum error of 18.8% and average error of 10.4% in the response value for *k* = 0.8.



(a) *k* = 0.5 (b) *k* = 0.7 (c) *k* = 0.9

Figure 4. Linear regression for the categorical variables.

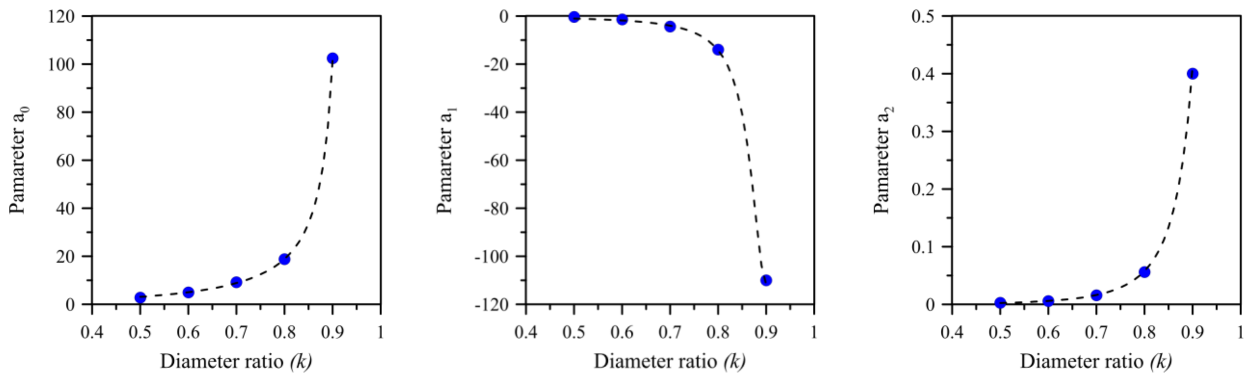
The second stage of the analysis procedure was to determine how the parameters a_i behave with the variation of *k*. With the aid of a statistical software an iterative procedure was applied to the data of Tab. 2 in order to predict the variation of each parameter according to the variation of *k*.

The regression models that best fit each parameter are shown in Eqs. (9) to (11).

$$a_0 = \frac{k}{0{,}4256 - 0{,}6071k + 0{,}1600k^2} \tag{9}$$

$$a_1 = \frac{-0{,}2018}{1 - 2{,}2158k + 1{,}2297k^2} \tag{10}$$

$$a_2 = \frac{0{,}0015k^{1{,}8350}}{(1-k)^{2{,}5260}} \tag{11}$$



(a) (b) (c)

Figure 5. Regression parameters fitting.

Finally, the a_i parameters were applied to Eq. (8), inserting the variable k in pressure drop prediction model. Thus, a correlation for the pressure drop, involving three independent variables with influence on the response in this study can be determined by Eq. (8) where the parameters a_0, a_1 e a_2 are given by Eq. (9), (10) and (11).

It is observed on the results that the parameter a_1 has a negative signal while the rest are positive multiplication factors. The presence of the negative sign in Eq. (10) indicates that an increase in eccentricity causes a reduction in ΔP value when other variables are held constant. Thus, the variable eccentricity, in isolated form, give a negative contribution to pressure drop, while the variable diameter ratio and the Reynolds number contributed positively. Among all the data analyzed, only three points showed great discrepancy with respect to the others. This can be treated as an isolated case and the cause of this discrepancy should be further analyzed.

The average error obtained when using the general fitting model was 5.4%, while the highest error was 22.9%. Only 2.4% of the data presented error larger than 15%, proving the validity of the model.

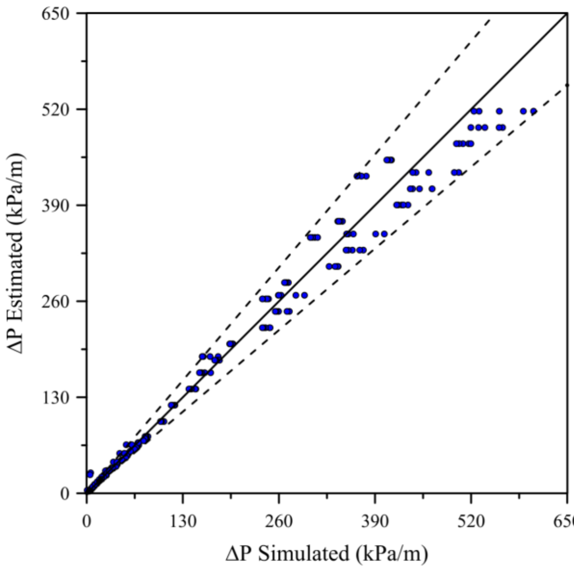


Figure 6. Response of the complete forecasting model.

5. CONCLUSIONS

The effect of various parameters on the pressure drop in an annular flow was observed through a set of simulations. A forecasting equation was proposed to predict the pressure drop as a function of diameter ratio, eccentricity of inner cylinder and Reynolds number. The inner cylinder rotation showed no significant influence on the pressure drop. Increasing the diameter ratio and the Reynolds number contributed to the increase of pressure drop while the eccentricity increase lead to a decrease in the pressure drop.

The adjusted regression model was efficient to predict the pressure drop in annular flow in the range of values of the variables studied in this work. The average error of 5.4% obtained in fitting the data show the validity of the model.

The velocity distribution in the annular space was more affected by the variation of the eccentricity of the annular and diameters ratio. The increase of the eccentricity lead to the occurrence of stagnation flow region that show negative effects on the cuttings transport process, impairing the efficiency of the cleaning process.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Bicalho, I.C., dos Santos, D.B.L., Ataíde, C.H., Duarte, C.R., 2015, "Estudo de simulação por CFD de escoamentos em poços horizontais", Proceedings of the 6th Encontro Nacional de Hidráulica de Poços de Petróleo e Gás, Rio Quente, GO, Brazil.

Costa, M. T. A. T. L., Rigato, S. F., Siqueira, R. N. 2013. Efeito da rotação sobre o torque da coluna de perfuração em poços horizontais, Anais do V Encontro Nacional de Hidráulica de Poços de Petróleo e Gás, Teresópolis-RJ.

Devore, Jay L. Probabilidade e estatística: para engenharia e ciências. Pioneira Thomson Learning, 2006.

Escudier, M. P., Gouldson, I. W., Oliveira, P. J., Pinho, F. T. 2000. "Effects of inner cylinder rotation on laminar flow of a Newtonian fluid through an eccentric annulus", International Journal of Heat and Fluid Flow, Vol. 21, pp. 92-103.

Escudier, M. P., Oliveira, P. J., and Pinho, F. T., 2002. "Fully developed laminar flow of purely viscous non-Newtonian liquids through annuli, including the effects of eccentricity and inner-cylinder rotation". International Journal of Heat and Fluid Flow, Vol. 23, pp. 52-73.

Gabriel, A.C., Siqueira, R.N., 2015, "Influência do índice de comportamento do modelo power-law na eficiência do processo de perfuração", Proceedings of the 6th Encontro Nacional de Hidráulica de Poços de Petróleo e Gás, Rio Quente, Brazil.

GhasemiKafrudi, E., Hashemabadi, S.H., 2016, "Numerical study on cuttings transport in vertical wells with eccentric drillpipe", Journal of Petroleum Science and Engineering, Vol. 140, pp. 85-96.

Hamed, S. B., Belhadri, M., 2009, "Rheological properties of biopolymers drilling fluids". Journal of Petroleum Science Engineering", Vol. 67, pp. 84-90.

Lidio, M.S., Siqueira, R.N., 2015, "Drill pipe eccentricity effects on horizontal wells cleaning process", Proceedings of the 23rd ABCM International Congress of Mechanical Engineering, Rio de Janeiro, Brazil.

Loureiro, B. V., Siqueira, R. N., Fontenelle, F. C. N., 2006. Efeito da rotação coluna de perfuração na suspensão de cascalhos sedimentados em poços horizontais, Encontro Nacional de Hidráulica de Perfuração e Completação de Poços de Petróleo e Gás, Domingos Martins-ES.

Loureiro, B.V. and Siqueira, R.N., 2006. "Determinação da tensão de cisalhamento mínima para arraste de partículas de um leito sedimentado". Proceedings of the Encontro Nacional de Hidráulica de Perfuração e Completação de Poços de Petróleo e Gás – ENAHPE 2006. Domingos Martins, Brazil.

Madlener, K.; Frey, B. and Ciezki, H. K., 2009. "Generalized Reynolds number for non-Newtonian fluids". Progress in Propulsion Physics, Vol. 1, pp. 237–250.

Nouar, C., Desaubry, C., Zenaidi, H., 1998, "Numerical and experimental investigation of thermal convection for a thermodependent Herschel-Bulkley fluid in an annular duct with rotating inner cylinder", European Journal of Mechanics - B/Fluids, Vol. 17, n. 6, pp. 875–900.

Pereira, F.A.R, Ataíde, C.H. and Barrozo, M.A.S., 2007. "CFD predictions of drilling fluid velocity and pressure profiles in laminar helical flow". Brazilian Journal of Chemical Engineering, Vol. 24, n. 4, pp. 587-595.

Pereira, F.A.R. 2006. Escoamento laminar de líquidos não-newtonianos em seções anulares: estudos de CFD e abordagem experimental. Ph.D. thesis, Federal University of Uberlândia, Uberlândia.

Pereira, F.A.R., Ataíde, C.H. and Barrozo, M.A.S. 2006. "Abordagem de CFD com modelo de fase discreta para análise do escoamento anular". Proceedings of the I Encontro Nacional de Hidráulica de Perfuração e Completação de Poços de Petróleo e Gás – ENAHPE2006. Domingos Martins, Brazil.

Pereira, M.S. 2006. Aplicação de secagem por microondas no tratamento de cascalho de perfuração. Ph.D. thesis, Federal University of Uberlândia, Uberlândia, MG, Brazil.

Sun, X., Wang, K., Yan, T., Shao, S. and Jiao, J., 2014. "Effect of drill pipe rotation on cuttings transport using computational fluid dynamics (CFD) in complex structure wells". Journal of Petroleum Exploration and Production Technology, Vol. 4, pp. 255-261.

Tardy, P. and Bittleston, S., 2015. "A model for annular displacements of wellbore completion fluids involving casing movement". Journal of Petroleum Science and Engineering, Vol. 126, pp. 105-123.

Thomas, J.E., 2001, "Fundamentos de Engenharia de Petróleo". 2ª edição, PETROBRAS. Editora Interciência, Rio de Janeiro, 2001.

Zanete, H.Z., Siqueira, R.N., 2015, "Escoamento axial de fluidos não-newtonianos em anulares excêntricos com rotação do cilindro interno", Proceedings of the 6th Encontro Nacional de Hidráulica de Poços de Petróleo e Gás, Rio Quente, Brazil.

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