Modeling of Drilling Cuttings Transport by Foam in Horizontal Well Condition Using Computational Fluid Dynamics

Ehsan Vaziri, Mohammad Simjoo*, Mohammad Chahardowli

Faculty of Petroleum and Natural Gas Engineering, Sahand University of Technology, Tabriz, Iran

ABSTRACT

Efficient cuttings transport is one of the most important parameters affecting drilling rate of wells. Foam has a great potential to reduce drilling problems compared to conventional drilling fluids due to its unique properties such as low density and high viscosity. In this paper, cuttings transport with foam was studied using a computational fluid dynamics approach. In this study the Eulerian multi-phase model was used to describe cuttings-fluid mixture flow. Foam rheology was expressed by the non-Newtonian power law model. Effects of foam quality and injection velocity, cuttings size, pipe eccentricity and rotational speed of drillpipes were studied. Modeling results were also compared with experimental data. Results showed that increase of foam quality improved hole-cleaning operation mainly due to the enhanced foam viscosity. Increase of foam injection velocity led to a reduction in in-situ cuttings concentration. This was due to the foam capability to destruct stationary cuttings bed. It was found that pipe eccentricity resulted in the accumulation of cuttings in the annulus. But, increase of the drillpipe rotational speed provided a better hole-cleaning, so that by increasing the rotational speed to 40 RPM, cuttings concentration decreased by 1.8 and 1.4 times in concentric and eccentric pipe, respectively.

KEYWORDS

Computational fluid dynamics, Drilling cuttings transport, Foam, Horizontal well

* Corresponding Author: email: simjoo@sut.ac.ir

Introduction

A proper cuttings removal is a major concern during horizontal well drilling, which could decrease both drilling time and cost. An inefficient hole-cleaning process leads to formation of a static cuttings bed in the wellbore, which causes several problems such as pipe stuck and decreasing the rate of penetration [1]. Foam as an underbalanced drilling fluid benefits from a higher viscosity and a lower density, which could lead to a minimized pipe stuck and also a lower fluid lost. Therefore, foam increases the drilling rate and also the well production rate [2]. Chen et al. studied the application of foam for cuttings transport in horizontal and concentric wellbore section. They reported that increasing foam quality and also foam injection velocity have a positive effect on the cuttings transport efficiency [3]. Duan et al. used a wellbore simulator to investigate the effect of pipe rotation on the cuttings transport using foam in a horizontal eccentric annular section. They reported that pipe rotation significantly decreases the cuttings concentration in a horizontal annulus during foam drilling [4]. Heydari et al. numerically investigated the impact of drillpipe rotation and eccentricity on the cuttings transport in a horizontal annulus. They reported that that the drillpipe eccentricity could increase the cuttings accumulation in the pipe [5]. As to the previous works, several successful achievements have been made from the lab-based studies; however, it is necessary to perform further numerical studies on foam performance for cuttings transport while considering both foam parameters and also drilling parameters. This paper introduces an applicable CFD model to investigate the effect of foam on drilling cuttings transport in horizontal wells. The model was validated using a set of laboratory data. Then, the model was implemented to investigate the effect of several drilling and well parameters on cuttings transport using foam.

Methodology

In this study, a 3-D CFD model was prepared to investigate the application of foam for the drilling cuttings transport process. The geometry of the model consisted of two pipes: a casing (as the outer boundary) and a drillpipe (as the inner boundary). Therefore, the drilling fluid could flow through the space between pipes, i.e., the annulus. The Eulerian multi-phase approach was used to describe the "cuttings-foam" flow. In addition, the foam rheology in the wellbore was described using the power law model. As to the drilling operation, drilling cuttings enter the annulus space in the form of a mass flow inlet boundary condition and then they are removed from the wellbore under a constant pressure boundary condition. An iterative numerical scheme was used to obtain the foam velocity and the cuttings velocity by solving the momentum and the mass conservation equations along a discretized flow path. To this end, the foam quality was expressed using a ratio of gas volume to total fluid volume:

$$\Gamma = \frac{V_g}{V_g + V_l} \tag{1}$$

The foam annular velocity was expressed as follows:

$$v_f = \frac{Q_g + Q_l}{A} \tag{2}$$

Equation 3 shows the foam rheology model used in this study:

$$\mu = K\gamma^{N-1} \tag{3}$$

Table 1 shows the value of *n* and *K* parameters for different foam quality of 70, 80 and 90%.

Table 1. The power law exponent and consistency index for describing foam rheological behavior[3]

Foam quality (%)	*n* (-)	*K* (pa.s^n)
70	0.45	0.835
80	0.40	2.185
90	0.36	3.732

Results and Discussion

Figure 1 shows the effect of foam injection velocity and foam quality on the cuttings concentration in a concentric horizontal well. Results showed that increase of foam injection velocity has a positive impact on the removal of drilling cuttings from the well annulus due to a higher drag and lift forces exerted on the solid particles. Therefore, it provides a better hole-cleaning process using foam. In addition, results showed that with the increase of foam quality, a higher cuttings removal efficiency was obtained. This positive effect could be attributed to the fact that the increase in foam quality enhances foam viscosity, which leads to a higher cuttings removal performance.

Figure 2 shows the effect of drillpipe rotation on the cuttings concentration in a concentric horizontal well. As to the results, the exerted rotary speed leads to a positive impact on the cuttings removal from the well annulus. This positive effect could be mainly due to the increase in the tangential velocity exerted on the solid particles and thus enhancement of the drag force.

Figure 3 shows the effect of drillpipe eccentricity on the cuttings concentration in a horizontal well. As to the results, pipe eccentricity has a strong influence on the cuttings transport. It was found that foam velocity profile was unevenly distributed through the eccentric annulus such that foam velocity in the lower section of the annulus was much smaller than the velocity in the upper section. Consequently, solid particles became rapidly deposited in the lower section due to the much lower lift and drag forces. This causes an excessive cuttings accumulation in the eccentric wellbore as shown by Figure 3.

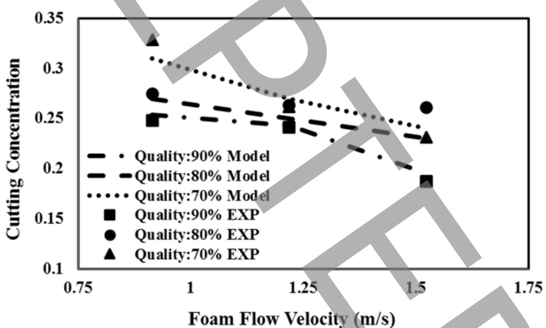

Figure 1. Effect of foam injection velocity and foam quality on cuttings concentration in a concentric horizontal well

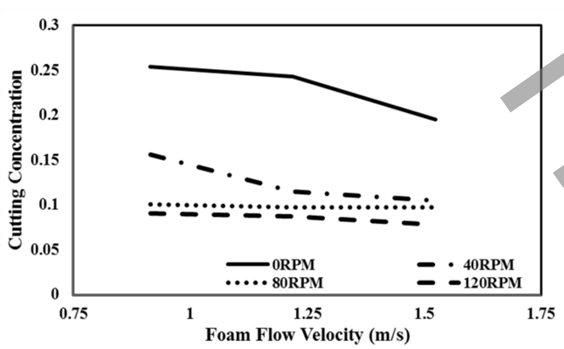

Figure 2. Effect of drillpipe rotation on cuttings concentration in a concentric horizontal well using 90% foam quality

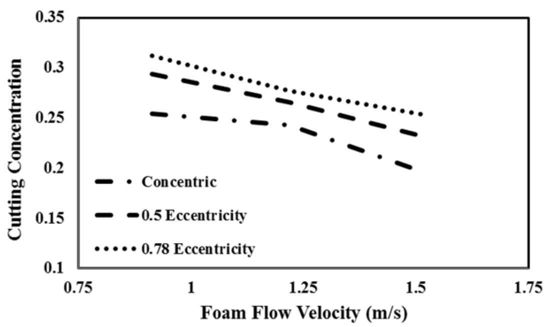

Figure 3. Effect of drillpipe eccentricity on cuttings concentration in a horizontal well using 90% foam quality

Figure 4 shows the effect of drillpipe rotation on the cuttings concentration in an eccentric horizontal well. Rotation of the drillpipe affects the axial velocity of solid particles, which significantly destroys the generated static cuttings bed through the eccentric wellbore. Such significant contribution could be due to the fact that the presence of a rotational speed leads to an orbital movement of the drillpipe. Also, the cuttings bed of an eccentric wellbore is in close contact with the drillpipe which causes an extra drag force to be exerted on the cuttings particle and thus provide a better movement of the solid particle through the annulus. All these effects lead to a better performance of cuttings transport in an eccentric horizontal well with drillpipe rotation.

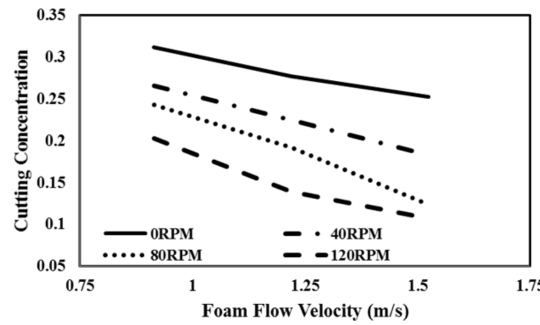

Figure 4. Effect of drillpipe rotation on cuttings concentration in an eccentric horizontal well using 90% foam quality

Conclusions

- Increase of foam velocity from 0.92 to 1.53 m/s (3 to 5 ft/s) provided an extra drag and lift forces on the cuttings particles, leading to a reduction in cuttings concentration by 1.3 times in a horizontal concentric wellbore.
- Increase of foam quality from 70% to 90% in a horizontal concentric wellbore led to a reduction in cuttings concentration by 1.2 times mainly due to the viscosity enhancement of the injected foam fluid.
- Drillpipe rotation exhibited a positive impact on the foam cuttings transport in a horizontal wellbore. As to results, an increase in rotational speed to 40 RPM caused to a reduction in cuttings concentration by 1.8 and 1.4 times in concentric and eccentric pipes.

References

[1] S. Walker, J. Li, The effects of particle size, fluid rheology, and pipe eccentricity on cuttings transport, in: SPE/ICoTA Coiled Tubing Roundtable, Society of Petroleum Engineers, 2000.

[2] T. Yan, K. Wang, X. Sun, S. Luan, S. Shao, State-of-the-art cuttings transport with aerated liquid and foam in complex

structure wells, Renewable and Sustainable Energy Reviews, 37 (2014) 560-568.
[3] Z. Chen, R.M. Ahmed, S.Z. Miska, N.E. Takach, M. Yu, M.B. Pickell, J.H. Hallman, Experimental study on cuttings transport with foam under simulated horizontal downhole conditions, SPE Drilling & Completion, 22(04) (2007) 304-312.
[4] M. Duan, S. Miska, M. Yu, N.E. Takach, R.M. Ahmed, J.H. Hallman, Experimental study and modeling of cuttings transport using foam with drillpipe rotation, SPE Drilling & completion, 25(03) (2010) 352-362.
[5] O. Heydari, E. Sahraei, P. Skalle, Investigating the impact of drillpipe's rotation and eccentricity on cuttings transport phenomenon in various horizontal annuluses using computational fluid dynamics (CFD), Journal of Petroleum Science and Engineering, 156 (2017) 801-813.