ISSN 2229-5518

Investigation of cutting weight impact on the cutting transport efficiency in deviated well

Ashfaque Ali, Abdul Haque Tunio, Intizar Ali Tunio

Abstract— Cutting transport in horizontal and deviated drilling wellbore is the challenging task due reduced mud flow velocity vertical component. This result, accumulation of the cuttings on the lower side of the wellbore that, causes the formation of the cutting bed. Subsequently, relative problems occurs such as pipe stuck, excessive drill bit wear and increased torque and drag requirements. In this regards, present research work aim to analyze the effect of cutting weight on the cutting transport efficiency and bed development. For that purpose Computational Fluid Dynamic (CFD) simulation is performed through Lagrangian/Eulerian technique is employed to model two phase cutting transport phenomena. Discrete Phase Modeling (DPM) is performed to track the cutting particle behavior and the Reynolds Average Navier-Stokes (RANS) equations were solved simultaneously. Turbulence present in continuous Eulerian phase was modeled through $k-\omega$ Shear Stress Transport (SST) model. CFD simulation results showed close agreement with the experimental data. Simulation results reveal that with increment of 600kg/m^3 cutting density results 6.3% decrease in CTE for same mud flow rate. Study results indicated that increase cutting density raised cutting particle concentration near the drill bit. Finally it is concluded that cutting weight has significant impact on CTE and also on the development of the cutting bed.

Index Terms— Cutting Transport Efficiency; CFD Simulation; Discrete Phase Modeling (DPM); Cutting Weight; deviated well.

---

1 Introduction

Efficient cutting transport is major sign of good drilling operation due to complex drilling process. Therefore it is essential to optimize drilling process parameters at low cost with sustainability. Inadequate cutting transport causes various drilling problems such as cutting accumulations, pipe stuck , excessive drill bit wear, high torque and drag requirements and re-drilling[1] . In this regards number researchers have found that cutting transport is affected by various parameters such as drill pipe diameter, hole diameters, well inclination, drill pipe rotation, pipe eccentricity, cutting parameters (size, shape and density) as well as fluid rheological properties [2-11]. The cutting during the drilling operation are brought to earth surface through annulus between the well and the drill pipe, with the aid of drilling fluid that is pumped through drill pipe.

Another study analyzed [12] the effect of drill pipe rotation on cutting transport efficiency where it was concluded that drill string rotation has major effect on cutting transport of smaller size particles. Moreover it was also found that well with 45-60^o inclination are difficult for cutting transport. Effect of fluid rheological properties on cutting transport for oil based drilling fluid was analyzed through CFD. Author concluded that viscosifier addition has improved hole cleaning performance up to certain level its further additions results no favorable effect, in addition to that viscosifier addition enhanced pressure losses[13]. [14] performed experimental study to investigate effect well inclination, mud flow rate and mud viscosity effects on cutting transport for horizontal and highly deviated wells. Analysis results revealed that cutting transport efficiency increases up to 8% by increasing mud viscosity at constant flow rate in turbulent flow regime, Whereas further increase in id viscosity results decrease in CTE by 12% due change in flow characteristics.

Experimental analysis was conducted [15] in full scale horizontal flow loop to analyze effect of mud velocity, cutting size, ROP, well size and drill pipe eccentricity. Results reveal that CTE increase with increase in mud flow rate, decreasing ROP, pipe eccentricity and smaller ratio of drill pipe diameter to wellbore diameter. Moreover they also proposed model to predict cutting volumetric concentration and cutting bed height on the basis of dimensional analysis. [16] performed numerical study by using Eulerian-Eulerian multiphase model, to evaluate effect of diameter ratio in horizontal well on cutting concentration and pressure loss. Study found that at lower diamter ratio drilling mud has better CTE than water; however at diameter ratio of 0.9 both fluid have similar CTE. [17] demonstrated effect of drill pipe rotation on cutting transport and critical fluid velocity experimentally and numerically. Analysis results found that drill pipe rotation improves cutting transport efficiency and reduce the critical fluid velocity required for efficient cutting transport.

Mishra [18] performed numerical study to analyze effect of mud velocity, ROP, cutting size, well inclination angle and drill pipe rotation on cutting transport by using Eulerian multiphase approach. Study found that mud flow rate, well inclination angle, and ROP has major influence on cutting transport. It was also found that drill pipe rotation significantly affect small particles transport. [19] illustrated similar findings.[20]first time used CFD to understand the flow mechanism inside the annulus and also investigated effect of mud rheological properties and particle size on cutting transport through employing solid-liquid multiphase model. Bilgesu used water and non-newtanion power law fluid to analyze cutting transport behavior in horizontal as well as in vertical well. Their results showed that mud flow rate has significant effect on cutting transport. Further extending their work [19]to analyze effect various drilling parameters their study draws similar conclusion found by[18].

Pang, Wang *et al.* [21]conducted numerical study using kinetic theory of granular flow to analyze effect of drill pipe rotation on cutting transport for sliding mesh. Their study found that increase in mud velocity cutting bed height reduced and increase in mud viscosity has favorable effect on cutting transport but results increase in pressure losses. Furthermore it was also observed that increase in cutting size reduce CTE and increase pressure drop. [22]performed numerical simulation to analyze effect mud velocity on CTE where it was found that increase in mud velocity results increase in cutting transport. Uduak and Skalle [23] conducted experimental and numerical analysis for modelling of fluid flow with annulus. Analysis results revealed that non-Newtonian fluid velocity is higher in boundary layer than Newtonian fluid which enforces better effect on CT. In addition to that it was also found that spherical shape cuttings are to transport.

Benjamin Werner [24]experimentally investigated and compared the performance of water based and oil based drilling fluid on hole cleaning. Their study showed that oil based mud provide better hole cleaning as well as it showed visco-elastic properties yield stress and a linear visco-elastic range. Whereas water based (WB)mud has no yield stress possesses 50 to 100% higher elasticity than (WB). [25]performed CFD simulation to analyze effect of cutting shape on the CT, Where they found that cutting shape has major influence on their transport. In addition to that they found that particle with lower shape factor are difficult to transport at higher inclination angle where particles with low shape factor are easier to transport at lower inclinations angles.

Recently a numerical study is conducted to investigate effect of drill pipe rotation, eccentricity, drilling rate, density, solid particle size, mud density, rheology, and velocity on cutting transport process by using Lagrangian–Eulerian/ discrete element method. Study results indicated that drill pipe rotation, drilling fluid rheology and velocity have significant role in hole cleaning process. In addition to that they also determined that proper selection of these parameter control 86.3% of CTE [26]. The impact of different polypropylene bead concentrations in water based mud (WBM) on hole cleaning is analyzed through experimental analysis. In addition to this impact of well inclination angle, cutting size and drill pipe rotation is also investigated, results indicated that smaller cuttings are easy to transport with drill pipe rotation and also it noted that polypropylene bead concentrations proved beneficial for horizontal as well as vertical well. Moreover, study varied drill pipe rotation rate from 0-150rpm where it is found that 60rpm value is optimal for effective hole cleaning[27].

Katende, Segar et al. [28] performed experimental study to investigate effect of addition of polypropylene beads with water based mud. Study was performed on the rig with 20ft length, 10 ppg drilling mud and 0.86 m/s annular velocity, the concentration of polypropylene beads was varied from 0 to 8ppb. Results indicated that increase in concentration of polypropylene beads enhanced cutting transport ratio. Moreover, study also found that cutting size has moderate effect on the cutting transport efficiency, but the cutting having size from 0.5-1.00mm are easier to transport as compared to cutting having size from 2.00-2.8mm[28]. CFD analysis was performed to analyze the effect of various drilling parameters on the particle transport such as particle characteristics, wellbore inclinations, and eccentricities. Simulation results revealed that the high yield stress and higher viscosity are the favorable for effective hole cleaning. Study results also indicated that the cutting transport is difficult in the deviated wells. Moreover, the mud velocity has positive influence on the cutting transport, but this become more effective at higher velocity values [29].

Furthermore, despite of the decades of the research still the various unsolved questions need mature solution such the correlation between mud velocity and cutting weight, what should be the optimum mud properties, how high should be mud velocity to avoid cutting buildup etc specifically in various drilling projects[30, 31]. As the cutting transport is still a serious concern of overall economics of the drilling project and requires mature solution especially in deviated drilling wells. In this regards present study aim to analyze the effect of cutting weight on cutting transport efficiency in deviated drilling well.

2 MODELING OF THE WELLBORE

The flow geometry consists of annular pipe, the inner and outer diameter of the annular represent the drill pipe and the borehole respectively. During drilling process solid rock particles are produced at the end of drill string (i.e at drill bit) that are need to be transported to the earth surface in order to continue drilling the thousand feet long wells. In order to simulate cutting transport process in FLUENT geometry creation is the first step. The 3D model of the annular pipe was developed in ANSYS design modeler. The specifications of the annular pipe are given in Table. 1. Initially, two concentric circles were drawn according to given specification and then that geometry is extruded in order to develop 3D wellbore annular. Since the analysis is performed for 60º deviated wellbore annular, but the simple vertical wellbore annular is designed whereas the deviation is considered when by putting the velocity in terms of components. The designed wellbore annular is shown in Fig. 1.

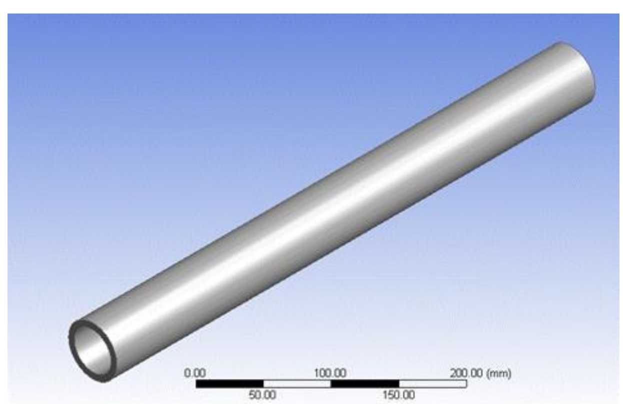


Fig.1 3D model of the wellbore annular

3 MESHING OF WELLBORE

The meshing of the wellbore annular is performed in ANSYS meshing tool, where complete physical domain is divided in small control volumes in order to solve all the fluid flow equation accurately over those control volumes. The cubical mesh elements were used to mesh the wellbore annular, the size of control volume is controlled through sizing tool. Moreover, the named sections in order to assign initial values were created at this stage. Inlet and outlet named section were created to start flow of mud that is carrying cuttings from depth of about 5000mm from the surface of earth. The meshed model of the wellbore annular is presented in Fig. 2.

4 BOUNDARY CONDITIONS & CFD MODELING

The boundary conditions used in this research were obtained from [14] and are specified in Table. 1. Since the simulation was performed to analyze the effect of cutting weight on the cutting concentration in deviated wellbore. The steady state CFD simulation is performed the gravity effects were encountered. Simulation of the cutting transport process contains two different phases one is mud fluid and other is the cutting rocks or simply cuttings. Thus simulation requires modeling both solid and liquid phases thus in present study Lagrangian-Eulerian approach is used to track the particle behavior through annular. In this connection, present study solved RANS for md fluid and DPM simultaneously. The turbulence present within mud fluid mud was modeled through *k*-ω SST solver. The discrete phase modeling was performed by creating injection from the inlet surface at the rate of 162g/min and the cutting particle specifications are given in Table. 1. Water is used as drilling fluid and the cutting density i.e cutting weight is also given in Table. 1

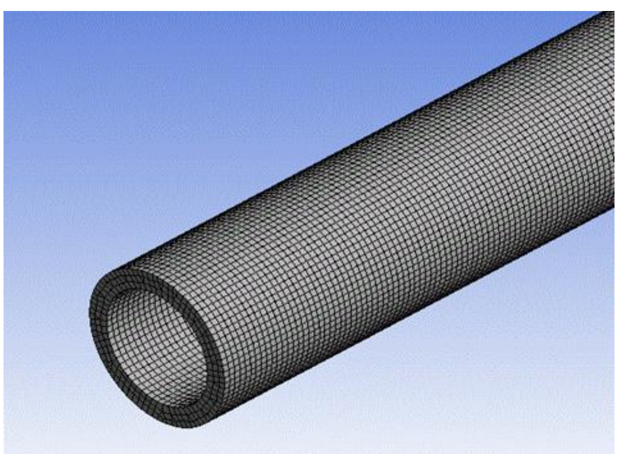


Fig. 2 Meshed model of the wellbore annular

TABLE 1
WELLBORE DESIGN SPECIFICATIONS & OPERATING CONDITIONS [14]

Parameter	Value
Well wall inner diameter	50.8 mm
Drill pipe diameter	38.1 mm
Well Depth	5000mm
Angle of inclination	60^o
Mud velocity	0.556m/s
Rate of Penetration (ROP)	0.0027kg/s
Cutting Density	2300 kg/m^3, 2600 kg/m^3 & 2800 kg/m^3
Particle diameter	1.70 mm
Cutting fluid density	1000 kg/m^3
Cutting fluid viscosity	1.03

5 COMPUTATIONAL MODEL

As the CFD simulation of the cutting transport problem involves the flow of incompressible fluid i.e mud and the solid particles (i.e sand particles), thus governing partial differential equation such as continuity and RANS equation for the present case of steady, viscous and three-dimensional incompressible flow was modeled in the following manner.

$$\frac{\partial U_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial}{\partial x_j}\left(\rho U_i U_j\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho \overline{u_i' u_j'}\right) \quad (2)$$

The values of *i,j=1,2,3*

The last term on the right hand side of in equation (2) denotes Reynolds stresses, this take into account the effect of turbulence present within flow. In order to accurately model Reynolds stresses various turbulence models were introduced through numerous research studies, however all the present models have some limitations. Among the various turbulence models $k-\omega$ Shear Stress Transport (SST) model is widely used to model industrial due to its reasonable accuracy and lower computational cost. The present study used $k-\omega$ SST model in order to model turbulence present within continuous phase. The Transport equations of $k-\omega$ SST model are given below

ISSN 2229-5518

$$\frac{\partial(ku_i)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\Gamma_k \partial k}{\rho \partial x_j}\right) + P + Y_k \quad (3)$$

$$\frac{\partial(\omega u_i)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\Gamma_\omega}{\rho}\frac{\partial \omega}{\partial x_j}\right) + G_\omega - Y_\omega + D_\omega \quad (4)$$

In these equations, P represents the generation of turbulent kinetic energy due to mean velocity gradients and G_ω represents the generation of ω. Γ_k and Γ_ω ω represent the effective diffusivity of k and ω, respectively. Y_k and Y_ω represent the dissipation of k and ω, respectively, due to turbulence. D_ω represents the cross-diffusion term.

6 Results & Discussions

In this section effect of cutting weight on the cutting transport efficiency/ performance is presented and discussed. Since the well data was obtained from research paper mentioned in section 2.1. It is also found that CFD simulation results shown good agreement with experimental results. Fig. 3 illustrates CTP against cutting weight for four different values of cutting density. From graph it is noticed that cutting transport efficiency decrease with increase in cutting weight. In addition to this, it is also noticed that CTE varies non-linearly with cutting weight. Cutting density in present study was varied from 2400kg/m³ to 3000kg/m³ with the interval of 200kg/m³. Analysis results revealed that in first two cases each increment of 200kg/m³ in density of cuttings causes approximately 1.3% decrease in CTE, however increase in density from 2800kg/m³ to 3000kg/m³ results decrease in CTE of about 3%. From the results it is concluded that increase in cutting weight after certain limit have significant impact on the cutting transport performance.

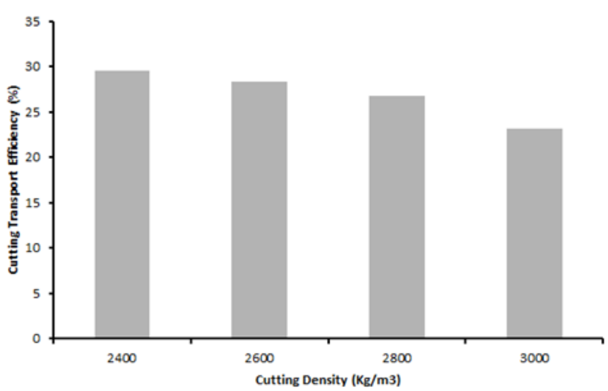
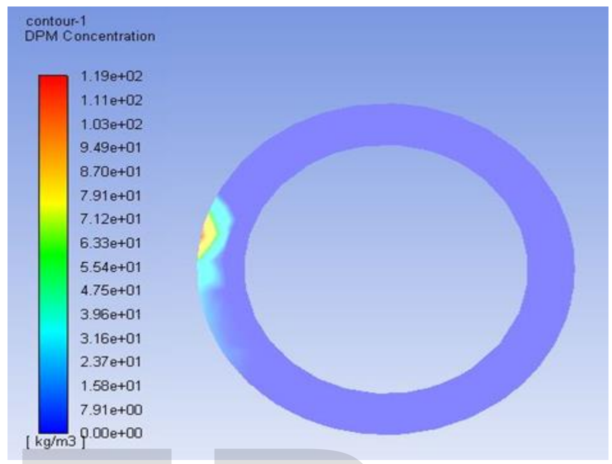
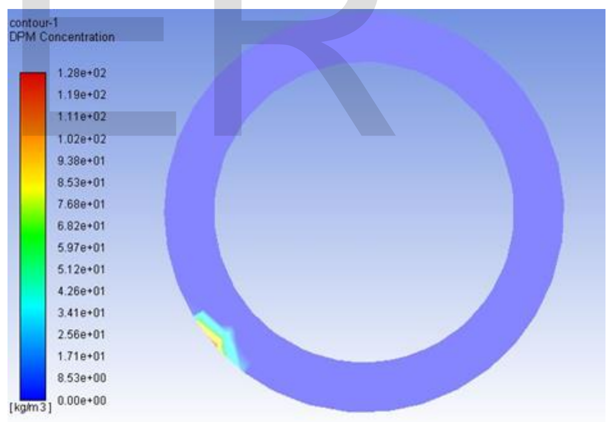


Fig. 3 Variation of the cutting transport efficiency against cutting density

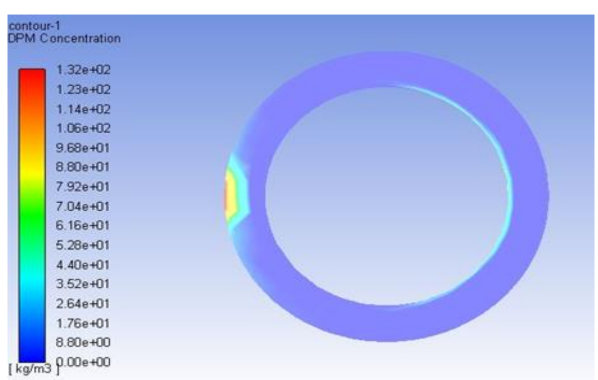
As the cutting transportation in deviated drilling well is still a challenging task in during drilling operation. As the well deviate from vertical position to any inclined position and to the horizontal cutting transport require higher mud flow rate for efficient cutting transport. In horizontal and deviated drilling wells the development of the cutting bed results severe problem in performing drilling operation. In this regards Fig. 4 shows the cutting concentration in 60° deviated drilling well at a distance of 500mm from the drill bit position. The cutting concentration is presented for three different cutting density values. From the contours it is clear that cutting concentration increase with increase in cutting weight.



(a)



(b)



(c)

Fig. 4 Cutting particle concentration at 500mm from the drill bit for different cutting particle density values (a) 2400kg/m^3 (b) 2600kg/m^3 (c) 2800kg/m^3

7 CONCLUSION

In this research, effect of cutting weight on cutting transport performance is analyzed for deviated wellbore through CFD simulation. Lagrangian/ Eulerian approach is used to model cutting transport process. Turbulence present in continuous phase was modeled through $k-\omega$ SST model and the coupled simulation is performed. CFD simulation was performed at four different values of cutting weight values. Study results showed close agreement with the experimental data that was presented in terms of cutting transport efficiency. Simulation results reveal that with increment 600kg/m^3 of cutting density results 6.3% decrease in CTE for same mud flow rate.
Study also found that cutting transport efficiency shown non-linear variation with the cutting weight in deviated wellbores. Moreover, study results indicated that increase cutting density raised cutting particle concentration near the drill bit. Finally it is concluded that cutting weight has significant impact on CTE and also on the development of the cutting bed.

8 FUTURE SCOPE

Authors expected that the findings of the present research work will help in understanding the importance of cutting weight on the cutting transport efficiency. It is expected that results of present work will help drilling engineers to devise optimum mud flow rate by keeping in view the cutting weight that will significantly reduce drilling processes expenditures.

9 CONFLICT OF INTEREST

The authors declare no conflict of interest.

10 REFERENCES:

[1] X. Chen, D. Gao, B. Guo, L. Luo, X. Liu, and X. Zhang, "A new method for determining the minimum gas injection rate required for hole cleaning in horizontal gas drilling," Journal of Natural Gas Science and Engineering, vol. 21, pp. 1084-1090, 2014.

[2] J. Capo, M. Yu, S. Z. Miska, N. Takach, and R. Ahmed, "Cuttings transport with aqueous foam at intermediate inclined wells," in SPE/ICoTA Coiled Tubing Conference and Exhibition, 2004.

[3] Z. Chen, R. M. Ahmed, S. Z. Miska, N. E. Takach, M. Yu, M. B. Pickell, et al., "Experimental study on cuttings transport with foam under simulated horizontal downhole conditions," SPE Drilling & Completion, vol. 22, pp. 304-312, 2007.

[4] R. Clark and K. Bickham, "A mechanistic model for cuttings transport," in SPE Annual Technical Conference and Exhibition, 1994.

[5] G. Espinosa-Paredes, R. Salazar-Mendoza, and O. Cazarez-Candia, "Averaging model for cuttings transport in horizontal wellbores," Journal of Petroleum Science and Engineering, vol. 55, pp. 301-316, 2007.

[6] V. Kelessidis and G. Mpandelis, "Flow patterns and minimum suspension velocity for efficient cuttings transport in horizontal and deviated wells in coiled-tubing drilling," in SPE/ICoTA Coiled Tubing Conference and Exhibition, 2003.

[7] M. Ozbayoglu, S. Miska, T. Reed, and N. Takach, "Using foam in horizontal well drilling: A cuttings transport modeling approach," Journal of Petroleum Science and Engineering, vol. 46, pp. 267-282, 2005.

[8] M. Ozbayoglu, A. Saasen, M. Sorgun, and K. Svanes, "Critical fluid velocities for removing cuttings bed inside horizontal and deviated wells," Petroleum Science and Technology, vol. 28, pp. 594-602, 2010.

[9] A. Ramadan, P. Skalle, S. Johansen, J. Svein, and A. Saasen, "Mechanistic model for cuttings removal from solid bed in inclined channels," Journal of Petroleum Science and Engineering, vol. 30, pp. 129-141, 2001.

[10] R. A. Sanchez, J. Azar, A. Bassal, and A. Martins, "The effect of drillpipe rotation on hole cleaning during directional well drilling," in SPE/IADC drilling conference, 1997.

[11] P. Tomren, A. Iyoho, and J. Azar, "Experimental study of cuttings transport in directional wells," SPE Drilling Engineering, vol. 1, pp. 43-56, 1986.

[12] B. Amanna and M. R. K. Movaghar, "Cuttings transport behavior in directional drilling using computational fluid dynamics (CFD)," Journal of Natural Gas Science and Engineering, vol. 34, pp. 670-679, 2016.

[13] K. Mohammadzadeh, S. Hashemabadi, and S. Akbari, "CFD simulation of viscosity modifier effect on cutting transport by oil based drilling fluid in wellbore," Journal of Natural Gas Science and Engineering, vol. 29, pp. 355-364, 2016.

[14] A. Piroozian, I. Ismail, Z. Yaacob, P. Babakhani, and A. S. I. Ismail, "Impact of drilling fluid viscosity, velocity and hole inclination on cuttings transport in horizontal and highly deviated wells," Journal of Petroleum Exploration and Production Technology, vol. 2, pp. 149-156, 2012.

[15] X. Song, Z. Xu, M. Wang, G. Li, S. N. Shah, and Z. Pang, "Experimental study on the wellbore-cleaning efficiency of microhole-horizontal-well drilling," SPE Journal, 2017.

[16] T. N. Ofei, S. Irawan, and W. Pao, "CFD method for predicting annular pressure losses and cuttings concentration in eccentric horizontal wells," Journal of Petroleum Engineering, vol. 2014, 2014.

[17] M. Sorgun, "Modeling of Newtonian fluids and cuttings transport analysis in high inclination wellbores with pipe rotation," Petroleum and Natural Gas Engineering, 2010.

[18] N. Mishra, Investigation of hole cleaning parameters using computational fluid dynamics in horizontal and deviated wells: West Virginia University, 2007.

[19] H. I. Bilgesu, N. Mishra, and S. Ameri, "Understanding the effect of drilling parameters on hole cleaning in horizontal and deviated wellbores using computational fluid dynamics," in Eastern Regional Meeting, 2007.

[20] H. Bilgesu, M. Ali, K. Aminian, and S. Ameri, "Com-

putational Fluid Dynamics (CFD) as a tool to study cutting transport in wellbores," in SPE Eastern Regional Meeting, 2002.

[21] B. Pang, S. Wang, Q. Wang, K. Yang, H. Lu, M. Hassan, et al., "Numerical prediction of cuttings transport behavior in well drilling using kinetic theory of granular flow," Journal of Petroleum Science and Engineering, vol. 161, pp. 190-203, 2018.

[22] X.-h. ZHU, S. Chao, and T. Hua, "Distribution features, transport mechanism and destruction of cuttings bed in horizontal well," Journal of Hydrodynamics, Ser. B, vol. 25, pp. 628-638, 2013.

[23] U. Mme and P. a. Skalle, "CFD calculations of cuttings transport through drilling annuli at various angles," International Journal of Petroleum Science and Technology, vol. 6, pp. 129-141, 2012.

[24] B. Werner, V. Myrseth, and A. Saasen, "Viscoelastic properties of drilling fluids and their influence on cuttings transport," Journal of Petroleum Science and Engineering, vol. 156, pp. 845-851, 2017.

[25] S. Akhshik, M. Behzad, and M. Rajabi, "CFD-DEM simulation of the hole cleaning process in a deviated well drilling: The effects of particle shape," Particuology, vol. 25, pp. 72-82, 2016.

[26] M. Naderi and E. Khamehchi, "Cutting transport efficiency prediction using probabilistic CFD and DOE techniques," Journal of Petroleum Science and Engineering, vol. 163, pp. 58-66, 2018.

[27] N. S. Heshamudin, A. Katende, H. A. Rashid, I. Ismail, F. Sagala, and A. Samsuri, "Experimental investigation of the effect of drill pipe rotation on improving hole cleaning using water-based mud enriched with polypropylene beads in vertical and horizontal wellbores," Journal of Petroleum Science and Engineering, vol. 179, pp. 1173-1185, 2019.

[28] A. Katende, B. Segar, I. Ismail, F. Sagala, H. Saadiah, and A. Samsuri, "The effect of drill–pipe rotation on improving hole cleaning using polypropylene beads in water-based mud at different hole angles," Journal of Petroleum Exploration and Production Technology, pp. 1-10, 2019.

[29] K. Mohammadzadeh, S. Akbari, and S. H. Hashemabadi, "Parametric study of cutting transport in vertical, deviated, and horizontal wellbore using CFD simulations," Petroleum Science and Technology, pp. 1-18, 2020.

[30] E. I. Epelle and D. I. Gerogiorgis, "A multiparametric CFD analysis of multiphase annular flows for oil and gas drilling applications," Computers & Chemical Engineering, vol. 106, pp. 645-661, 2017.

[31] A. Katende, N. V. Boyou, I. Ismail, D. Z. Chung, F. Sagala, N. Hussein, et al., "Improving the performance of oil based mud and water based mud in a high temperature hole using Nanosilica nanoparticles," Colloids and surfaces a: physicochemical and engineering aspects, vol. 577, pp. 645-673, 2019.