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Lifting capacity efficiency using polyethylene beads: A numerical investigation

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ABSTRACT

Global demand growth has driven the development of more inventive methods for enhancing oil well drilling at lower prices and avoiding operational issues that slow down oil well drilling. The present research is significant because the lifting capacity may be increased by inserting polymer beads into drilling mud instead of high-cost additives. The numerical cuttings trajectory simulation was performed using the commercial ANSYS FLUENT 2019 R3 software to account for the influence of cuttings collisions. To test the cuts transport behavior owing to the presence of liquid and solid phases, the (Eulerian-Eulerian) model was utilized. The mind transfer rate is determined in this simulation by varying the operating parameters (drilling mud flow rate and temperature, cuttings size and inclination, drill pipe rotation, and eccentricity) with and without polyethylene (PE) beads. The result shows that the average error ratio between the results of the numerical simulation is 5 % with the experimental results of researcher Ismail. The higher the percentage of PE beads entering the drilling fluid, the lower the concentration of the cuttings within the annular space of the simulation model. The concentration of cuttings within the annular space reaches 28 % when drilling fluid flows at a speed of 1.2 m/s without adding polyethylene PE beads. While it decreases to (17, 21, 24) % when adding beads by (6, 4, 2) %, respectively, at the same flow velocity of drilling fluid. The decrease in the concentration of cuttings within the annular space of the simulation model reaches 14 % when PE beads are inserted with drilling fluid by 6 % and the drill pipe rotation speed is 0 rpm, While the percentage increases to 65 % when the drill pipe rotation speed is increased to 120 rpm at the same ratio of PE beads entering with the drilling fluid. The reduction percentage of the cuttings concentration within the annular space of the simulation model reaches 30 % when 6 % of PE beads are entered into the drilling fluid at a temperature of 20 ℃, while the percentage is reduced to 14 % when the drilling fluid temperature is 50 ℃ at the same percentage of PE beads is inserting. The inserting of polyethylene (PE) beads with the drilling fluid has increased the ability of the drilling fluid to move the cuttings, but it is affected by the amount of drilling angle, as we found that the effect of the polyethylene (PE) beads is effective and clear when the drilling angle is 0˚ (vertical). While its effect becomes less at the drilling angle of directional wells and becomes very weak at the drilling angle of 90˚ (horizontal). The inserting of polyethylene (PE) beads with drilling fluid has a good and positive effect on large-sized cuttings when compared with the impact of the beads with smaller-sized cuttings.

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Nomenclature

v_m	Mixture velocity (m/s).
ρ_m	Mixture density (kg/m^3).
v_s	Solid velocity (m/s).
ρ_s	Solid density (kg/m^3).
v_l	Liquid velocity (m/s).
ρ_L	Liquid density (kg/m^3).
G_k	Generation of k due to mean velocity gradients.
$C_{1,\epsilon}, C_{2,\epsilon}$	Constant.
ϵ	Volume concentration
α_s	Volume concentration of cuttings.
α_L	Volume concentration of drilling fluid.

Subscripts

CFD	Computational Fluid Dynamics.
E-E	Eulerian-Eulerian.
MTM	Mixture Turbulence Model
DTM	Dispersed Turbulence Model.
WBM	Water-based mud.
CVC	Cuttings Volumetric Concentration.
CC	Cuttings Concentration.
RPM	Revolutions per Minute.
e	eccentricity.

1. Introduction

Interest in resolving problems associated with cleaning the bottom of the well and conveying the cutting to the surface has lately increased while using directional and horizontal oil well drilling technologies. Cleaning the well throughout the drilling process is a critical factor in influencing the cost, duration, and quality of the oil well drilling process. Effective cleaning requires immediately getting the cutting to the well's surface. Numerous academics have extensively used numerical calculations and approaches to tackle a wide variety of drilling fluid flow problems, as well as their relationship to cutting transport under a variety of operating conditions. Mehmet Sorgun. [1] Explained how cuttings from horizontal and deviated wells are transported to the surface using experimental and computational methods. The Middle East Technical University in Petroleum and Natural Gas Engineering performed the experiment. Use water and other drilling fluids to investigate the characteristics and behavior of cuttings. Drilling pipe rotation (0-120 rpm) and borehole inclination (0-60) degrees were also investigated. A mathematical approach to forecast drilling fluid flow in a horizontal concentric ring has been suggested. The Navier-Stokes equations for turbulent flow were numerically solved (Matlab 2007). The drilling fluid flow rate has been shown to be the most important factor in cutting transport. The rotation of the drill pipe also lowers the production of fixed cuttings, however, this benefit diminishes with flow rate. The theoretical model also effectively forecasts frictional pressure loss and loop velocity profile. Hussain H. et al. [2] used continuity equations, Navier-Stoke, and the force law to describe non-Newtonian fluids to convey cuts to the well surface. FLUENT software was used to simulate. Three kinds of drilling mud were used in the studies. A drilling location in Sudan provided the feeding conditions and cutting size. The influence of cuttings shape was tested at (600-900) GPM and cuttings size (2.54, 4.45, and 7) mm. The findings revealed that fine clippings are the easiest to raise and clean the well. The finest cleaning results were observed while drilling at 30 degrees and using an 800 GPM flow rate. Xiaofeng Sun et al. [3] simulated drilling fluid flow numerically using a multi-phase Euler model. The most essential characteristics impacting cuttings layer development are flow rate, hoof slope, and rotation speed. The drill pipe was simulated at an inclination of 45-90 degrees and a rotation speed of 80-240 rpm with a flow rate of 30-50 L/s. This rotation increases cutting transmission and helps disperse cuttings asymmetrically during runoff. The impact of rotating the drill pipe is strong when the drilling fluid flow rate is low or medium. Satish and Shobha. [4] Drilling mud flow via a spinning inner ring was analyzed. The influence of several parameters on cuttings transport efficiency was evaluated, including drill pipe rotation speed, drilling mud flow rate and type, and cuttings concentration inside the test loop. The data were evaluated to explain the mixture's pressure drop, slip velocity, and kinetic energy distribution inside the test ring. For multi-phase liquids, the (FLUENT 12.0) software employed the (Eulerian-Eulerian) model, and the (SIMPLEC) method for speed and pressure. The simulation model was evaluated against existing research data. Oil-based drilling fluids boost the cohesiveness of undesirable cuttings layer. However, water-based drilling fluid aids in cuttings loosening. The transfer efficiency of the cuttings varies depending on various characteristics. Titus and Ismail. [5] Used (ANSYS CFX-15) software to simulate a multi-phase liquid (Eulerian-Eulerian) model. The particle size ranged from 90 to 270 microns, and their concentration ranged from 10% to 40%. The k-epsilon model was selected to apply to existing experimental data. The findings indicated that as particle size grew, flow pressure loss increased. Reducing the cutting size helps decrease pressure loss. Behnam and Mohammad. [6] Used a numerical model to solve liquid and solid flow equations (cuttings). The (Eulerian-Eulerian) model was adopted to predict particle behavior during flow. The degree of convergence was verified by comparing numerical findings to experimental data. Flow rate, pipe rotation, slope, and cutting size were all tested extensively. The findings indicated that cuttings transfer efficiency reduces between 45-60 degrees. Increasing burr rotation and flow velocity also improves cleaning efficiency. Mostafa Keshavarz et al. [7] employed a (k-e) turbulent model and a multiphase (Eulerian-Eulerian) model to describe three-phase flow inside a concentric ring. To verify the numerical simulation, the results were compared to earlier operations. These included drill pipe rotation, water and air flow rate, cutting size, and inclination. The findings revealed that rotating the drill pipe between (0-75) rpm reduces cuttings concentration, whereas rotating between (75-125) rpm increases cuttings concentration. The rotation of the drill pipe has a stronger impact on little particles than on big items. The concentration within the well rises with increasing airflow, reduced inclination, and drill pipe rotation. Emmanuel and Dimitrios. [8] ANSYS FLUENT 17.1 was used to evaluate two-phase flow in a well loop. These factors included drill pipe deviation, tilt, rotation, rate of penetration (ROP), and drilling fluid rheology. Particle motion was modeled using an Eulerian-Eulerian multi-phase tracking model. The numerical model was validated by comparing simulation results to experimental data (error rate less than 11 percent). The findings indicated that the drilling fluid velocity, pipe inclination, and deflection are the most important elements affecting cuttings' transit efficiency. Ali Zakerian et al. [9] employed simulation software to explore parameter effects on cutting transport. The drilling fluid type, cutting density, and concentration ratio were studied using fluent software. The findings revealed that increasing the drilling fluid density lowered cuttings concentration in the test tube by 32.9 percent while decreasing pressure. Increasing the cuttings density from the operational density increases the cuttings concentration within the ring by 200 percent. It is feasible to tailor the drilling fluid density to the cuttings density. Boxue Pang et al. [10] the influence of flow rate, inclination, rotation of the drill pipe, and drilling fluid viscosity on cuttings uplift. To verify the numerical model's accuracy. The findings converged well with earlier experimental data. The findings revealed that increasing the flow rate helps minimize cutting layer thickness. Another finding is that transporting cuttings at an angle of (35-65) degrees is the most problematic. Changing the drill pipe's rotation speed has no impact on transferring cuttings. Siamak and Majid. [11] Simulated cutting transport using CFD-DEM (CFD-DEM). The drag force, lift, and pressure gradient associated with the two-phase flow were utilized. The model investigates cuttings collision and transmission, as well as cuttings bed mechanics. Drilling fluid velocity, inclination, and rotation were examined. The findings demonstrated that when the drill pipe rotates, a layer of cuttings forms inside the inner walls of the ring, which thickens with decreasing flow velocity. After the drill pipe's rotation speed reaches the crucial speed for high flow rate, no more rotational contribution is made. When the hoof slope is 40 degrees, rotating the drill pipe helps minimize cutting thickness. Mortatha Al-Yasiri et al. [12] employed computational fluid dynamics (CFD) to solve multi-phase flow issues. The influence of (the drilling fluid rheology, drill pipe rotation, flow rate, cuttings density, shape and focus) on the efficiency of lifting cuttings in vertical wells. Multi-phase liquid flow was simulated using DSPM and Eulerian-Eulerian models. The numerical findings demonstrated that a range of factors impact the efficiency of transporting cuttings. Among the factors, the drilling fluid flow rate has the greatest impact on cleaning efficiency. However, increasing the cuttings density and concentration within the simulated test model reduced the drilling fluid's capacity to move the cuttings. Xiaohua et al. [13] presented an experimental and numerical simulation study of the use of a pulsed drilling fluid to transport the cutting bed. A three-dimensional simulation model was created to transport the cuttings in the horizontal wells in conformity with the experimental model and studied the effect of the velocity of the pulse drilling fluid on the cutting velocity and its ability to break up the layer accumulations of the horizontal wells. The results showed that the use of a pulsed drilling fluid helps to increase the cutting speed, reduce its concentration, and improve the cleaning of the well bottom. Rasel A. et al. [14] created a fluid dynamics computer model that simulates multi-phase flow systems for parameter prediction. The computational model's correctness was verified by comparing numerical simulation results to experimental data. For multi-phase runoff, including liquid (water), gas (air), and solid (sand), the ANSYS FLUENT 16.2 software was utilized (sand). Particle size and concentration, flow rate, and pressure gradient were studied. The study's findings validated the suggested simulation model and demonstrated its use in many applications, including oil and gas. Mohsen and Moarefvand. [15] On well cleaning efficiency using computational and experimental methods. A numerical simulation using a Computational Fluid Dynamics (CFD) model of liquid and solid flow was done (Eulerian-Eulerian). Concerning viscosity, (k-epsilon) was addressed, and the suggested model was validated using experimental data. The experimental part involves developing a functional model with a stationary outer pipe and a spinning inner pipe powered by an electric motor. An electric motor and gearbox inject cuttings at varying rates. A variable capacity pump supplies drilling fluid to the annular vacuum. The test pipe may be slanted to suit the investigation. The findings indicated that viscosity boosts cleaning efficiency. However, the findings revealed an undesirable critical angle of drilling (30-55) degrees that should be avoided. Dongsheng Wen et al. [16] simulated the effect of nanoparticles on drilling fluid performance. Used computational fluid dynamics (CFD) to deal with multi-phase flows and flow issues. The influence of drilling fluid rheology, flow rate, cuttings density, shape, and concentration on drilling fluid efficiency was examined. The findings demonstrated that adding nanoparticles to the drilling fluid increased its rheological characteristics and hence its capacity to clean the well. Mastaneh Hajipour. [17] Used a concentric pipe to dig a horizontal well. (CFD) is used to solve two-phase flow equations with solid particles (cuttings). A horizontal ring with 1.9 in inner and 2 in outer diameter was created. Several models were used to determine the hydrodynamic inlet length, which came out to 40 ft. It was shown that drilling mud qualities (low and high viscosity) were affected by operational parameters such as penetration rate and drill pipe rotation. The ratio of solid particles inside the well ring was used to assess the cuttings' movement. The findings demonstrated that the drill pipe's rotation encourages solid particle movement and slows their sliding. Increasing the drilling mud flow rate reduces the influence of bore tube rotation. Increasing viscosity helps the components move but increases the drilling mud's resistance to rotation. Although substantial research has been done on cuttings transport and hole cleaning, further research is needed to validate the influence of operational factors on lifting capacity. On the other hand, we found that many of the materials added to drilling mud to improve the lifting capacity may be expensive or not applicable due to the large quantities required to be prepared for drilling mud. Also, we did not find interest in conducting studies on the inserting of materials with drilling mud without changing the chemical drilling mud specifications.

2. Numerical model

Numerous modeling approaches exist to describe multi-phase flow. The most significant of them are Euler-Lagrange, Euler-Euler, Volume of fluid, and Dispersed phase. In the present investigation, the Euler-Euler model was used. To analyze the flow behavior of cuttings and drilling mud in the annulus, the Eulerian-Eulerian (E-E) two-phase flow model was utilized. Interactions between the two phases are described by introducing extra source terms into the conservation equations.

2.1. Model geometry

The flow geometry is an annulus created by two cylinders. The inner and outer cylinders represent the drill pipe and borehole, respectively. Drilling fluid is poured into the drill pipe and the annulus transports drill cuttings to the surface. The annulus may be hundreds of feet in diameter and form a fully developed flow. As a consequence, a fully developed annulus section was simulated to save computation time. This was accomplished by modelling a horizontal annulus with an inner diameter of 0.05 m and an outside diameter of 0.1 m. A series of simulations was used to establish the hydrodynamic entrance length. The simulated well length was fixed at 4 m in this inquiry since the hydrodynamic entrance length is less than 4 m and the flow has been determined.

The drill string does not stay in the wellbore's centre during horizontal and directional drilling; it descends due to gravity. The eccentricity of a drill string is determined by the following equation:

$$\mathrm{e} = \frac{D}{R_O - R_i} \tag{1}$$

Where (R_i) is the drill pipe radius, (R_o) is the wellbore radius, and (D) is the distance between the drill pipe and wellbore centres.

The geometrical and operational parameters utilized in the simulation are listed in **Table 1**. The model is created with the use of a (Solid work) application, as seen in **Fig. 1**.

Table 1. Simulation input parameters.

Parameter	Value
Simulated well length (m)	4
Drill pipe diameter (m)	0.0508
Wellbore diameter (m)	0.1016
Mud drilling density (kg/m^3)	1200
Cutting density (kg/m^3)	2400
Mud drilling type	WBM
Drill pipe eccentricity (e)	0, 0.4.0.8
Mud drilling temperature (°C)	20, 30.40.50
Drill pipe rotation (rpm)	0, 40, 80,120
Mud drilling velocity (m/s)	0.3, 0.6, 0.9, 1.2
Hole inclination (˚)	0˚, 30˚, 45˚60˚, 90˚
Cuttings volume (mm)	(0.5-1), (1.5-2), (2.25-3), (3.5-4)

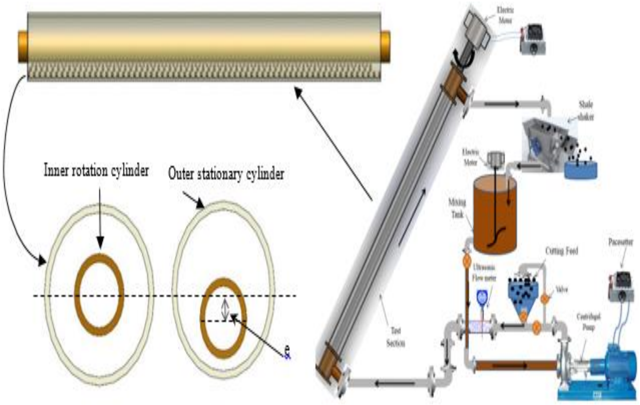

Figure 1. Base-case flow.

2.2. Mathematical modelling of turbulence [18].

Primarily, three different models of turbulence are performed for modelling multiphase (k -e) disorder. These model options are:

- Mixture Turbulence Model (MTM).
- Dispersed Turbulence Model (DTM).
- Turbulence model for each phase.

The mixture turbulence model (MTM) is the simplest of the three options. It uses mixture properties, mixing speeds and presumably captures the important features of the turbulent. It represents the first extension of a single-phase model (k-e) and is applicable when phases are separated to layers or semi-stratified stratum layers and when the density ratio between phases is close to one. In these cases, use of the mixture properties and mixture velocity is sufficient to capture the important advantage of the disturbance. The equations governing the mixture turbulence model (k-e) are given as follows:

$$\frac{\partial}{\partial t}(\rho_m k) + \nabla.(\rho_m.v_m.\epsilon) = \nabla.\left(\frac{\mu_{l,m}}{\sigma_k}\nabla k\right) + G_{k,m} - \rho_m.\epsilon \qquad (2)$$

And

$$\frac{\partial}{\partial t}(\rho_m \epsilon) + \nabla.(\rho_m.v_m.\epsilon) = \nabla.\left(\frac{\mu_{l,m}}{\sigma_\epsilon}\nabla\epsilon\right) + \frac{\epsilon}{k}(C_{1,\epsilon}G_{k,m} - C_{2,\epsilon}\rho_m.\epsilon) \qquad (3)$$

The mixture velocity and density (v_m and ρ_m) are computed respectively, by the following relationship:

$$\rho_m = \sum_{i=1}^{N}\alpha_i\,\rho_i \text{ and } v_m = \frac{\sum_{i=1}^{N}\alpha_i\,\rho_i\,v_i}{\sum_{i=1}^{N}\alpha_i\,\rho_i} \qquad (4)$$

This takes the following form for two phases (solid-liquid) flow case:

$$\rho_m = \alpha_s\,\rho_s + \alpha_L\,\rho_L \text{ and } v_m = \frac{\alpha_s\,\rho_s v_s + \alpha_L\,\rho_L\,v_l}{\alpha_s\,\rho_s + \alpha_L\,\rho_L} \qquad (5)$$

2.3. Meshes generated

Dynamic and static hexagonal meshes were employed in all flow modes. At the inlet and outflow boundaries, edge scaling and face meshing methods were utilized to generate a high-resolution image capable of capturing boundary conditions. It was vital to preserve a high degree of orthogonally and low skewness in the mesh; hence, the outer pipe divisions were equal to the interior pipe divisions. To determine the best number of elements necessary to deliver an accurate solution while using the fewest feasible computer resources, a grid size independence study was conducted on all pipe eccentricities considered **Fig. 2**. As seen in **Fig. 3**, the concentric flow configuration requires more elements than the eccentric annuli configuration in order to give an independent solution regardless of the grid size.

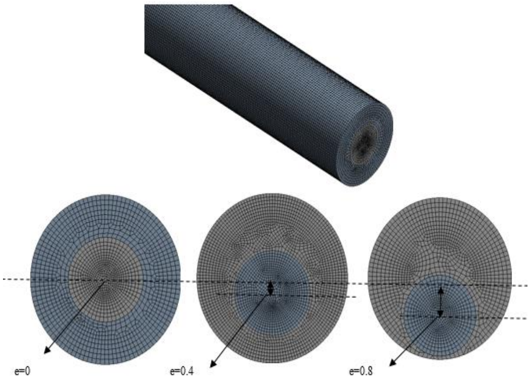

Figure 2. Sensitivity analysis of grid size

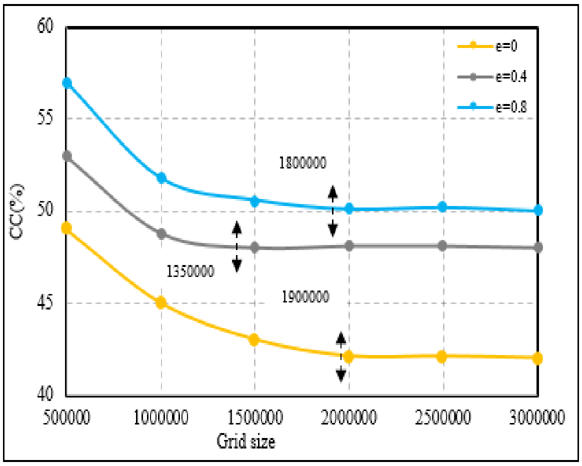

Figure 3. Mesh generated.

2.4. Boundary conditions

In this work, the boundary conditions are shown in **Fig. 4**. The velocity (Inlet Limits Type) and (Appropriate Size Portions) of the secondary stages have been imposed at the inlet. The outlet boundary pressure type of the outlet has been performed; its pressure value is set equal to the atmospheric pressure. Moreover, the non-slip condition of the interior and exterior walls has been considered.

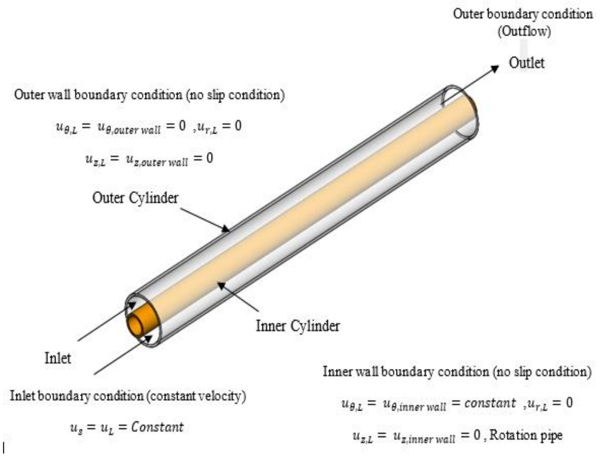

Figure 4. Boundary conditions.

2.5. Simplifications and assumptions

Simplifications and assumptions have been completed respectively. All have been listed below to solve this problem:

1- The liquid phase is an incompressible non-Newtonian fluid.
2- The cuttings are spheres shapes
3- Between two phases, there is no interfacial mass transport.
4- Slippage velocity is neglected.
5- Effect of shear stress and shear strain is neglected.
6- The kinetic energy of the particles is not conserved.

3. Material preparation

3.1. Drilling mud

A water-based mud (WBM) has been adopted, which is actually used to drill many oil and gas wells with great depths. The drilling fluid density of 1200 kg/m^3.

3.2. Polyethylene beads

A buoyant force is generated when a less dense object is immersed in a higher density medium. On this basis, the idea of introducing polyethylene beads with the drilling fluid came to generate a buoyant force towards the top that may be useful in increasing the thrust resulting from the drilling fluid to move the rock pieces to the top of the surface of the well. Linear low density polyethylene (LLDPE) beads were used 930 kg/m^3. Note that the particles entering with the drilling fluid are disc-shaped, with a diameter of 3 mm and a thickness of 1.5 mm.

4. Result and discussion

4.1. Numerical validation

In order to reach high reliability in the use of numerical simulation programs to explain the parameters associated with the process of drilling oil wells and their impact on the ability of drilling fluid to transport cuttings, simulations of experimental models were conducted for other researcher (Ismail et al. [19]) using the Eulerian-Eulerian model. **Fig. 5** show a comparison of the simulation of the experimental models of the cutting transport ratio (CTR) under the influence of changing the drilling angle. The results of the comparison of the above figures showed that the average error ratio between the results of the numerical simulation is 5 % with the experimental results of researcher Ismail. From this error, it is clear that there is reliability in the use of numerical simulation programs.

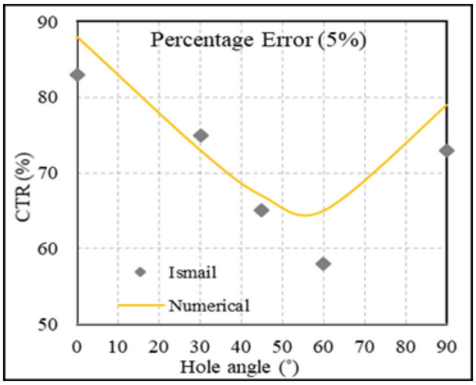

Figure 5. Comparison between experimental (Ismail et al. [19]) and numerical results for variation of the hole angle and CTR.

4.2. Numerical Results

Fig. 6 shows the concentration of cuttings within the annular space of the simulation model after inserting polyethylene (PE) beads with drilling fluid. In general, we noted that the higher the speed of the drilling fluid flow, the greater the ability of the drilling fluid to transport cuttings. On the other hand, the higher the percentage of PE beads entering with the drilling fluid, the lower the concentration of the cuttings within the annular space of the simulation model. This is because the buoyancy force as a result of the density difference between the polyethylene beads and the drilling fluid causes the beads to move upward at a speed higher than the velocity of the drilling fluid flow. Thus, the grains collide with the cuttings and prevent their slipping and increase the lifting force generated by the drilling fluid. Where we noted that the concentration of cuttings within the annular space reaches 28 % when drilling fluid flows at a speed of 1.2 m/s without adding polyethylene PE beads. While it decreases to (17, 21, 24) % when adding beads by (6, 4, 2) %, respectively, at the same flow velocity of drilling fluid. The concentration of the cuttings within the annular space of the simulation model before and after the inserting of different proportions of PE beads with the effect of the rotation speed of the drill pipe is shown in Fig. 7.From the above figure, we noticed that the higher the rotation speed of the drill pipe, the greater the ability of the drilling fluid to transport the cuttings to reduce the concentration of the cuttings within the annular space of the simulation model. Also, we noted that the inserting of PE beads contributed to reducing the concentration of cuttings, which has a greater impact when increasing the rotation speed of the drill pipe. noted, when comparing with drilling fluid without adding beads, The decrease in the concentration of cuttings within the annular space of the simulation model reaches 14 % when PE beads are inserting with drilling fluid by 6 % and the drill pipe rotation speed is 0 rpm, While the percentage increases to 65 % when the drill pipe rotation speed is increased to 120 rpm at the same ratio of PE beads entering with the drilling fluid. This is due to the fact that the forces dominating the cuttings are less effective when the drill pipe rotates. And in the presence of the lifting forces generated by the drilling fluid with the buoyancy force of the grains, the ability of the drilling fluid to move the cuttings increases.

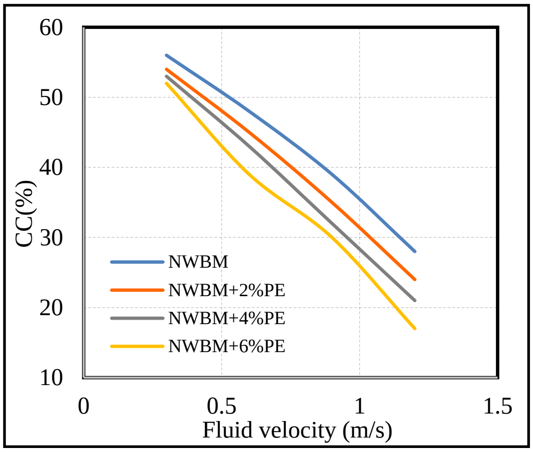

Figure 6. The (CC) after inserting (PE) beads with drilling fluid under changing the (Vm) (Vc = (0.5- 1) mm, rpm = 80, e=0, T=20 ℃, ϴ=0˚).

Fig. 8 shows the concentration of the cuttings after inserting polyethylene (PE) beads with drilling fluid. In general, we noted that the ability of the drilling fluid to transport cuttings decreases when the temperature of the drilling fluid increases. On the other hand, we noted that the increase in the percentage of PE beads added to the drilling fluid increases the ability of the drilling fluid to transport cuttings at all temperatures. Also, PE beads are more effective at lower drilling fluid temperatures compared to the high drilling fluid temperature, we noted that the reduction percentage of the cuttings concentration within the annular space of the simulation model reaches 30 % when 6 % of PE beads are entered into the drilling fluid at a temperature of 20 ℃, While the percentage is reduced to 14 % when the drilling fluid temperature is 50 ℃ at the same percentage of PE beads is inserting. Fig. 9 shows the concentration of the cuttings after inserting the polyethylene (PE) beads with drilling fluid under the influence of the change in the angle of inclination of drilling. We noted that the inserting of polyethylene (PE) beads with the drilling fluid has increased the ability of the drilling fluid to move the cuttings, but it is affected by the amount of drilling angle, as we found that the effect of the polyethylene (PE) beads is effective and clear when the drilling angle is 0˚ (vertical). While its effect becomes less at the drilling angle of directional wells and becomes very weak at the drilling angle of 90˚ (horizontal). The concentration of the cuttings within the annular space of the simulation model before and after the inserting of different percentages of polyethylene PE beads with the effect of the size of the cuttings is shown in Fig. 10. From this figure, we noted that the greater the size of the cuttings, the greater its concentration within the annular space of the simulation model. Also, we noted that polyethylene (PE) beads contribute to increasing the ability of the drilling fluid to transport cuttings at all sizes. The inserting of polyethylene (PE) beads with drilling fluid has a good and positive effect with large-sized cuttings when This is due to the fact that the cuttings of small size are pushed upwards due to the lifting force generated by the drilling fluid, and the role of the polyethylene (PE) beads is to accelerate the transport of the cuttings towards the top, while the effect of the buoyant force of the polyethylene (PE) beads is to prevent the slipping of the larger cuttings, reduce the impact of the force of attraction and weight, and increase the frequency of collisions to facilitate the task of the drilling fluid to transport the cuttings compared with the impact of the beads with smaller-sized cuttings.

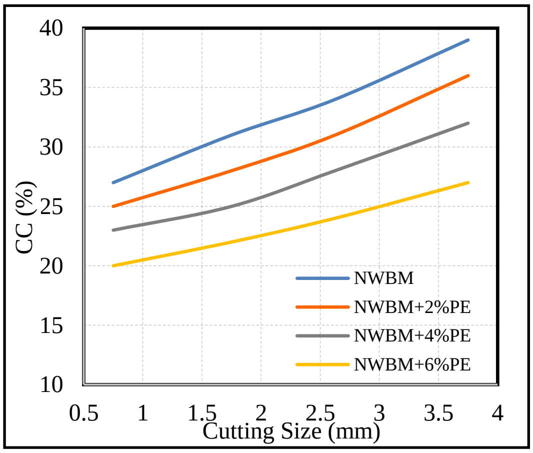

Figure 7. The (CC) after inserting (PE) beads with drilling fluid under changing the (rpm) (Vc= (0.5-1) mm, Vm=0.6 m /s, e=0, T=20 ℃, ϴ=0˚).

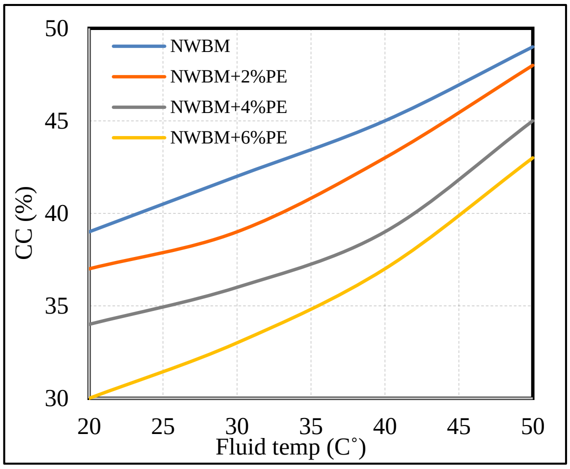

Figure 8. The (CC) after inserting (PE) beads with drilling fluid under changing the (T) (Vc= (0.5-1) mm, rpm = 80, e=0, Vm=0.9 m/s, ϴ=0˚).

4.3. Comparison of Reduction Ratio of Cuttings Concentration before and after Inserting (PE) Beads to Drilling Fluid.

Fig. 11 shows the comparison of the (PMC) of cuttings within the first meter of the simulation model that includes the following specifications (Vc= (0.5-1) mm, rpm=120, e=0, ϴ=˚90, T=20, Vm= 1.2 m/s) befor and after adding 6% of PE beads. In general, we noted that the inserting PE beads with drilling fluid contributed more to increasing the ability of the drilling fluid to transport cuttings when compared with the drilling mud without inserting PE beads.

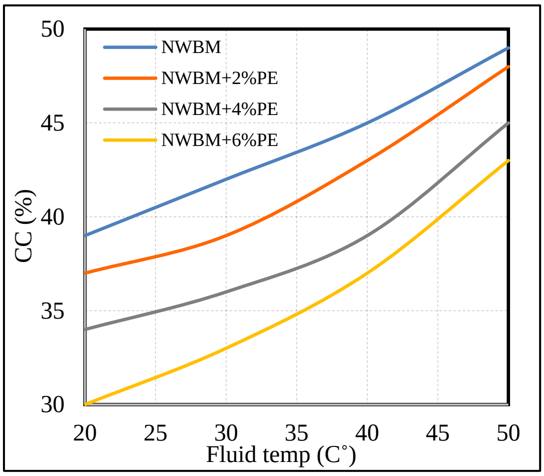

Figure 8. The (CC) after inserting (PE) beads with drilling fluid under changing the (T) (Vc= (0.5-1) mm, rpm = 80, e=0, Vm=0.9 m/s, ϴ=0˚).

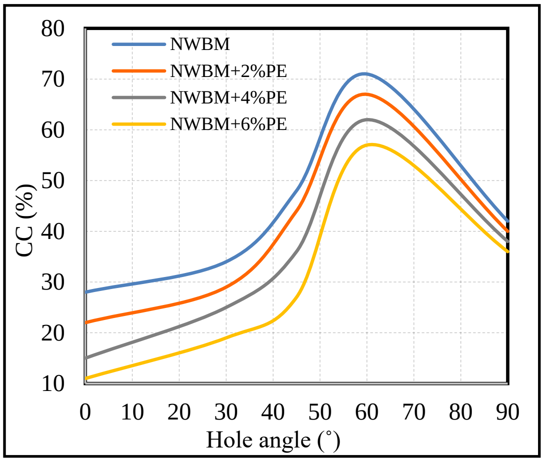

Figure 9. The (CC) after inserting (PE) beads with drilling fluid under changing the (hole angle) (Vc= (0.5-1) mm, rpm = 80, e=0 Vm=1.2 m/s, T=20°C).

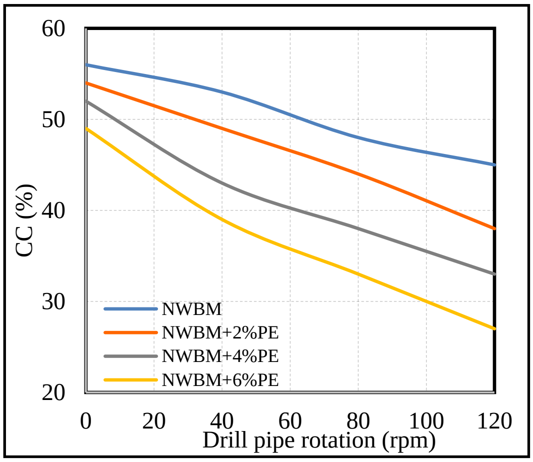

Figure 10. The (CC) after inserting (PE) beads with drilling fluid under changing the (Vc) (Vm=1.2 m/s, e=0, T=20 ℃, rpm = 80, ϴ=0˚).

According to the buoyancy theory, the greater the difference between the density of the liquid and the density of the submerged object, the greater the buoyant force is generated. Therefore, a greater buoyant force is generated when PE beads are inserted with the drilling fluid, which increases the frequency of collisions, prevents the slip and stability of the cuttings, and increases the lifting force of the drilling fluid.

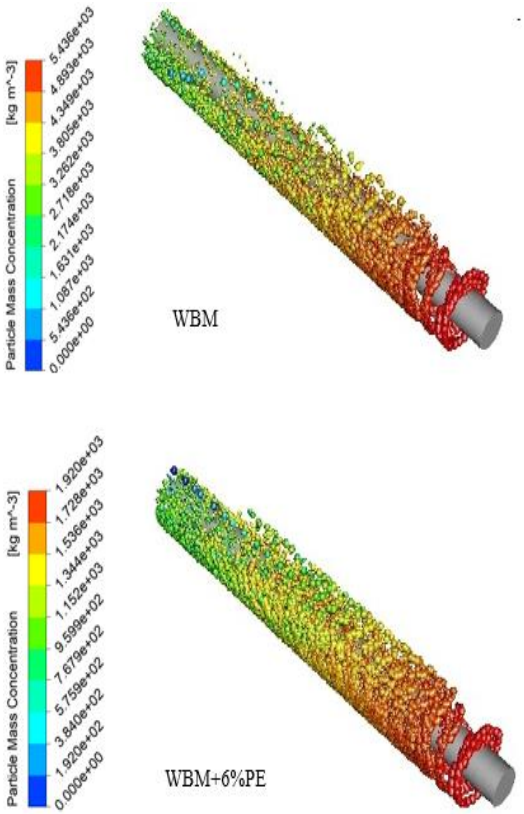

Figure 11. Comparison of the (PMC) of cuttings before and after adding 6% of PE beads. (Vc = (0.5-1) mm, rpm=120, e=0, ϴ=˚90, T=20, Vm= 1.2 m/s).

5. Conclusions

1. The average error ratio between the results of the numerical simulation is 5 % with the experimental results of researcher Ismail [19]. From these ratios, it is clear that there is reliability in the use of numerical simulation programs.
2. The higher the speed of the drilling fluid flow, the greater the ability of the drilling fluid to transport cuttings.
3. The higher the percentage of PE beads entering the drilling fluid, the lower the concentration of the cuttings within the annular space of the simulation model.
4. The concentration of cuttings within the annular space reaches 28 % when drilling fluid flows at a speed of 1.2 m/s without adding polyethylene PE beads. While it decreases to (17, 21, 24) % when adding beads by (6, 4, 2) %, respectively, at the same flow velocity of drilling fluid.
5. The decrease in the concentration of cuttings within the annular space of the simulation model reaches 14 % when PE beads are inserted with drilling fluid by 6 % and the drill pipe rotation speed is 0 rpm, While the

percentage increases to 65 % when the drill pipe rotation speed is increased to 120 rpm at the same ratio of PE beads entering with the drilling fluid.

6. The reduction percentage of the cuttings concentration within the annular space of the simulation model reaches 30 % when 6 % of PE beads are entered into the drilling fluid at a temperature of 20 ℃, while the percentage is reduced to 14 % when the drilling fluid temperature is 50 ℃ at the same percentage of PE beads is inserting.
7. The inserting of polyethylene (PE) beads with the drilling fluid has increased the ability of the drilling fluid to move the cuttings, but it is affected by the amount of drilling angle, as we found that the effect of the polyethylene (PE) beads is effective and clear when the drilling angle is 0˚ (vertical). While its effect becomes less at the drilling angle of directional wells and becomes very weak at the drilling angle of 90˚ (horizontal).
8. The inserting of polyethylene (PE) beads with drilling fluid has a good and positive effect on large-sized cuttings when compared with the impact of the beads with smaller-sized cuttings.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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