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Application of Computational Fluid Dynamics for Investigation the Effect of the Hole Cleaning Parameters in Inclined and Horizontal Wells

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Abstract

The increasing global demand has prompted the development of more innovative ways to enhance the drilling of oil wells at lower costs, and avoid operational problems that affect the speed of drilling oil wells. The numerical cuttings trajectories simulation has been done to include the effect of cuttings collisions using commercial ANSYS FLUENT 2019 R3 CFD software. The (Eulerian-Eulerian) model was used to verify the cuts transport behavior due to the existence of liquid and solid phases. In this simulation, the mind transport rate is checked by changing the operational parameters which including (drilling mud flow rate and temperature, cuttings size, inclination, drill pipe rotation and eccentricity). The results show that the high degree of agreement was observed between the numerical results with experimental studied by the researcher Yaacob, indicating the CFD analysis system's dependability and capacity to mimic the drilling operation. The use of (Eulerian-Eulerian) model is found reliable in interpreting the phenomena of multiphase flow for understanding the mechanism of influence of parameters associated with the process of drilling oil wells on the lifting capacity. Increasing the flow velocity of the drilling mud transforms the flow pattern from laminar to turbulent, and the latter is one of the desired flow patterns during the flow that enable to increase the lifting capacity of the cuttings. The effect of the rotation speed of the drill pipe on the concentration of cuttings decreases when the flow rate of drilling fluid increases. the cuttings concentration when the flow velocity is 0.6 m/s reaches 48 % when the cuttings size is (0.5-1) mm and it attained to (60,57.52) % when the cuttings size is ((3.5-4) ,(2.25-3),(1.5-2)) mm respectively for the same flow velocity. The increase in the temperature of the drilling fluid weakened the ability of the drilling fluid to move the cuttings. At the flow velocity is 1.2 m/s and the drilling angle is 0˚ (vertical well), the cuttings concentration attained to 30 % within the annular space, while the concentration becomes (41, 44, 54, 32) % at the drilling angle (30˚, 45˚, 60˚, 90˚) respectively at the same stated flow velocity.

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Keywords: CFD; ANSYS-Fluent; Eulerian-Eulerian; Well Cleaning.

تطبيق ديناميكيات الموائع الحسابية للتحقق من تأثير تنظيف الفتحة في الآبار المائلة والأفقية

الخلاصة

دفع الطلب العالمي المتزايد إلى تطوير طرق أكثر ابتكاراً لتعزيز حفر آبار النفط بتكاليف أقل ، وتجنب المشاكل التشغيلية التي تؤثر على سرعة حفر آبار النفط. تم إجراء محاكاة مسارات العقل عددياً لتشمل تأثير تصادمات القصاصات بتطبيق برنامج ANSYS FLUENT 2019 R3 CFD التجاري. تم استخدام نموذج (Eulerian-Eulerian) للتحقق من سلوك نقل العقل لوجود مرحلتين سائلة وصلبة. في هذه المحاكاة، يتم فحص معدل نقل العقل عن طريق تغيير المعلمات التشغيلية التي تشمل (معدل تدفق طين الحفر، درجة الحرارة، حجم القطع، الميل، دوران أنبوب الحفر والانحراف).

أوضحت النتائج أن درجة التوافق العالية لوحظت بين النتائج العددية والتجريبية التي درسها الباحث يعقوب مما يدل على موثوقية نظام تحليل CFD وقدرته على محاكاة عملية الحفر. إن استخدام نموذج (Eulerian-Eulerian) يمكن الاعتماد عليه في تفسير ظاهرة التدفق متعدد الأطوار لفهم آلية تأثير العوامل المرتبطة بعملية حفر آبار النفط على قدرة الرفع. تؤدي زيادة سرعة تدفق طين الحفر إلى تحويل نمط التدفق من صفحي إلى مضطرب، وهذا الأخير هو أحد أنماط التدفق المطلوبة أثناء التدفق مما يساعد على زيادة قدرة الرفع للقطع. يتناقص تأثير سرعة دوران أنبوب الحفر على تركيز القطع عندما يزداد معدل تدفق مائع الحفر. تركيز العقل عند سرعة التدفق 0.6 م / ث تصل إلى 48٪ عندما يكون حجم العقل (0.5-1) مم ويصل إلى (57.60, 52)٪ عندما يكون حجم العقل ((3.5-4) ، (2.25- 3)، (1.5-2)) مم على التوالي لنفس سرعة التدفق. تؤدي الزيادة في درجة حرارة مائع الحفر إلى إضعاف قدرة مائع الحفر على تحريك القطع. عند سرعة التدفق 1.2 م / ث وزاوية الحفر 0° (بئر رأسي)، يصل تركيز القطع إلى 30٪ داخل الفراغ الحلقي، بينما يصبح التركيز (41 ,44 ,54 ,32)٪ بزاوية الحفر (30° ,45° ,60° ,90°) على التوالي بنفس سرعة التدفق المذكورة.

1. Introduction

When employing the directional and horizontal oil well drilling methods, focused on investigating difficulties cleaning the bottom of the well and transporting the cutting to the surface has recently grown. Cleaning the well during the drilling process is one of the most important elements determining the cost, time, and quality of drilling oil wells. Cleaning effectively entails bringing the cutting to the well's surface as rapidly as feasible. Numerical computations and methodologies have been extensively employed by numerous academics to solve many of the drilling fluid flow difficulties, as well as their link to cutting transport under different operating situations. Based on mechanical theory and a three-layer method, developed a mathematical model to describe cutting particle movement in the annular flow during horizontal drilling. The model was solved numerically using MATLAB computer methods. In a concentric ring, the model helps assess the performance of irregular-shaped cuts. An annular size, cut size and shape, rate of penetration (ROP), and drilling fluid rheology influence have been properly modelled. The drilling fluid viscosity, cuttings size, and ring size all influenced the transportation operations. Among other characteristics impacting transportation, penetration rate had the least influence. It has also been shown that the mathematical model may be used to plan or study the

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transport process of cuttings in horizontal wells [1]. 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 best cleaning results were observed while drilling at 30 degrees and using an 800 GPM flow rate [2]. Simulated the influence of many settings on the ability to move items to the well surface.

A simulated well with a depth of 2000 m and a diameter of 380 mm was built with a 200 mm spinning inner tube. The GAMBIT 2.4.6 application was used to construct the mesh and send it to ANSYS (FLUENT). The suggested approach uses a distinct phase model to track cutting travel. Along with three drilling fluids, the influence of flow, cutting size, shape, and eccentricity of the rotating tube on cutting components was explored. To validate the simulation technique, the results were compared to earlier operations.

The findings demonstrated that turbulence in the drilling fluid helps circulate the ring and raise the cut. The findings also show that tiny particles and spheres are the simplest to clean [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 assists in disperse cuttings asymmetrically during runoff. The impact of rotating the drill pipe is strong when the drilling fluid flow rate is low or medium [4].

Simulated drilling mud behavior and cuttings transport efficiency using the Fluent CFD software suite. The current study focused on centric and eccentric rings and the parameters of the drilling mud. The simulation model was compared to earlier experimental investigations for verification and demonstrated an error rate of 8%, indicating that employing simulation software (CFD) to represent physical variables of drilling fluids is reliable. Cuttings transport rate rises with rheological properties and flow rate of drilling mud. The cutting ratio falls from (0-45) degrees further from the head. From 0-120 rpm, the cutting transmission rate improves from 72-79 percent [5].

Offered a numerical investigation of the influence of drill pipe rotation on the efficiency of

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conveying cuttings to the well surface in horizontal drilling. A numerical simulation was run on (ANSYS 15.0 CFX). The program's correctness was confirmed by comparing the cut concentrations and pressure losses at (0 and 60) rpm for the hoof tube to earlier operations. Numerical and experimental findings agreed well, with an agreement rate of around 12%. Increasing the burring tube rotation speed from 0 to 120 rpm reduced the cutting concentration by 84.3 percent with a loss of pressure at 2.43 m/s. When the flow rate is large, the influence of the drill pipe rotation is minor [6].

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 [7].

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 with existing experimental data. The findings indicated that as particle size grew, flow pressure loss increased. Reducing the cutting focus helps decrease pressure loss [8]. 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 [9].

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.

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The rotation of the drill pipe has a stronger impact on little particles than big items.

The concentration within the well rises with increasing air flow, reduced inclination, and drill pipe rotation [10]. 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 modelled 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 [11].

Employed a 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 [12].

It is feasible to tailor the drilling fluid density to the cuttings density. 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 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 [13].

Simulated cutting transport using CFD-DEM (CFD-DEM). The drag force, lift, and pressure gradient associated with 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 [14].

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

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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 [15].

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 [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 [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. 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 [18].

Although extensive research has been carried out for studies over the past few years on the topics of cuttings transport and hole cleaning, there is a need for further study to verify the impact of operational parameters accompanying the drilling process of oil wells and to determine the most influential on the ability of drilling mud to transport pieces. There is also a limited understanding of the impact of operational parameters on the ability of drilling mud to transport pieces in directional and horizontal wells. The effect of high drilling mud temperature on the lifting capacity of the shale blocks has rarely been studied despite the high temperature during the drilling process. The current study includes determining the extent to which most operating parameters affect the lifting capacity and what is the effect of each parameter on the other in

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vertical, horizontal and directional wells. Also, verifying the accuracy of using CFD programs to simulate the oil well drilling process. One of the novelties in this study is the containment of particle collisions in order to develop a more accurate physics-based numerical model of particle flow in a rotating system.

2. Numerical Model

Several modeling techniques are available to explain multi-phase flows, the most important of which are: Euler-Lagrange, Euler-Euler, Volume of fluid and Dispersed phase. In the current study, a model was adopted Euler-Euler. The Eulerian-Eulerian (E-E) two-phase flow model was used to analyses the flow behavior of cuttings and drilling mud in the annulus. In the (solid-liquid) model, cuttings are treated as a continuum, just as they are in the liquid phase. Thus, interpenetrating liquids and solids exist in two phases, each with its own conservation equation of motion. Interactions between the two phases are explained by supplementing the conservation equations with additional source terms.

2.1. Drilling Liquid Conservation Equations [19].

- **For the liquid phase, the continuity equation is as follows:**

$$\frac{\partial}{\partial t}(\varepsilon_l \rho_l) + \nabla(\varepsilon_l \rho_l v_l) = 0 \qquad (1)$$

Where (ε_l) is the liquid phase volume concentration, (v_l) is the liquid velocity vectors, and (ρ_l) is the liquid density.

- **The conservation equation for the moment is stated as:**

$$\frac{\partial}{\partial t}(\varepsilon_l \rho_l v_l) + \nabla(\varepsilon_l \rho_l v_l v_l) = \varepsilon_l \nabla . \tau_l + \varepsilon_l \rho_l \mathrm{g} - \varepsilon_l \nabla \mathrm{p} - \beta(v_l - v_s) \qquad (2)$$

Where (g) is gravity's acceleration, (β) is the drag coefficient between cuttings and fluid, and (τ_l) is the liquid's stress tensor.

- **A power-law fluid's constitutive equation may be expressed as:**

$$\tau_l = \eta(D).D \qquad (3)$$

Where (τ_l) is the fluid's shear stress, (η) is it's apparent viscosity, and (D) is the rate of deformation tensor. **D is defined by:**

$$D = \left(\frac{\partial v_{lj}}{\partial x_i} + \frac{\partial v_{li}}{\partial x_j}\right) \qquad (4)$$

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In general, η is a function of the rate of deformation tensor's three invariants, and is a function of the shear rate's function:

$$\eta = K(\sqrt{0.5\, D * D})^{n-1} \tag{5}$$

The consistency factor (K) is equal to the power-law index (n). When n 1¼, the rheological characteristics of the fluid are separated into two halves, it is a Newton fluid. When n > 1, it is shear thickening fluid, and when n 1, it is shear thinning fluid.

2.2. Cuttings Phase Conservation Equations [19].

- **Cutting phase's mass conservation equation is represented as:**

$$\frac{\partial}{\partial t}(\varepsilon_s \rho_s) + \nabla(\varepsilon_s \rho_s v_s) = 0 \tag{6}$$

Where (ε_s) and (v_s) are the cuttings' volume concentration and velocity vectors, respectively, and (ρ_s) is the cuttings' density.

- **The tension in the cuttings phase is denoted by the symbol τ_s:**

$$\tau_s = \xi_S \nabla v_s I + \mu_s \left[(\nabla v_s + (\nabla v_s)^T) - \frac{2}{3}(\nabla v_s) I \right] \tag{7}$$

Where (I) is a one-dimensional vector. (ξ_S) and (μ_s) are the bulk solids and shear viscosities of cuttings, respectively.

2.3. Coefficient of Interphase Momentum Transport [19].

The (Huilin-Gidaspow) drag correlation may be used to determine the drag force between drilling mud and cuttings.

$$C_d = \frac{24}{Re_s}\left(1 + 0.15 {Re_s}^{0.687}\right) \tag{8}$$

In the cuttings phase, the Reynolds number is defined as:

$$Re_s = \frac{d_s \varepsilon_l \rho_s [v_l - v_s]}{\mu_l} \tag{9}$$

3. <u>Model Geometry</u>

The flow geometry was assumed to be an annulus formed by two cylinders. The inner and outer cylinders, respectively, depict the drill pipe and borehole. Drilling fluid is pumped into the drill pipe and conveys drill cuttings to the surface through the annulus. The annulus may span hundreds of feet and create a fully evolved flow. As a result, a segment of the annulus with fully grown length was modelled to save computing time. A horizontal annulus with an inner diameter of 0.05 m and an outer diameter of 0.1 m was modelled in this respect. The hydrodynamic entry

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length was determined by a series of simulations. Because the hydrodynamic entry length is less than 4m and the flow has been established, the simulated well length was set to 4m in this investigation.

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

$$e = \frac{D}{R_O - R_i} \tag{10}$$

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 centers.

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 Figure (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 (℃)	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)

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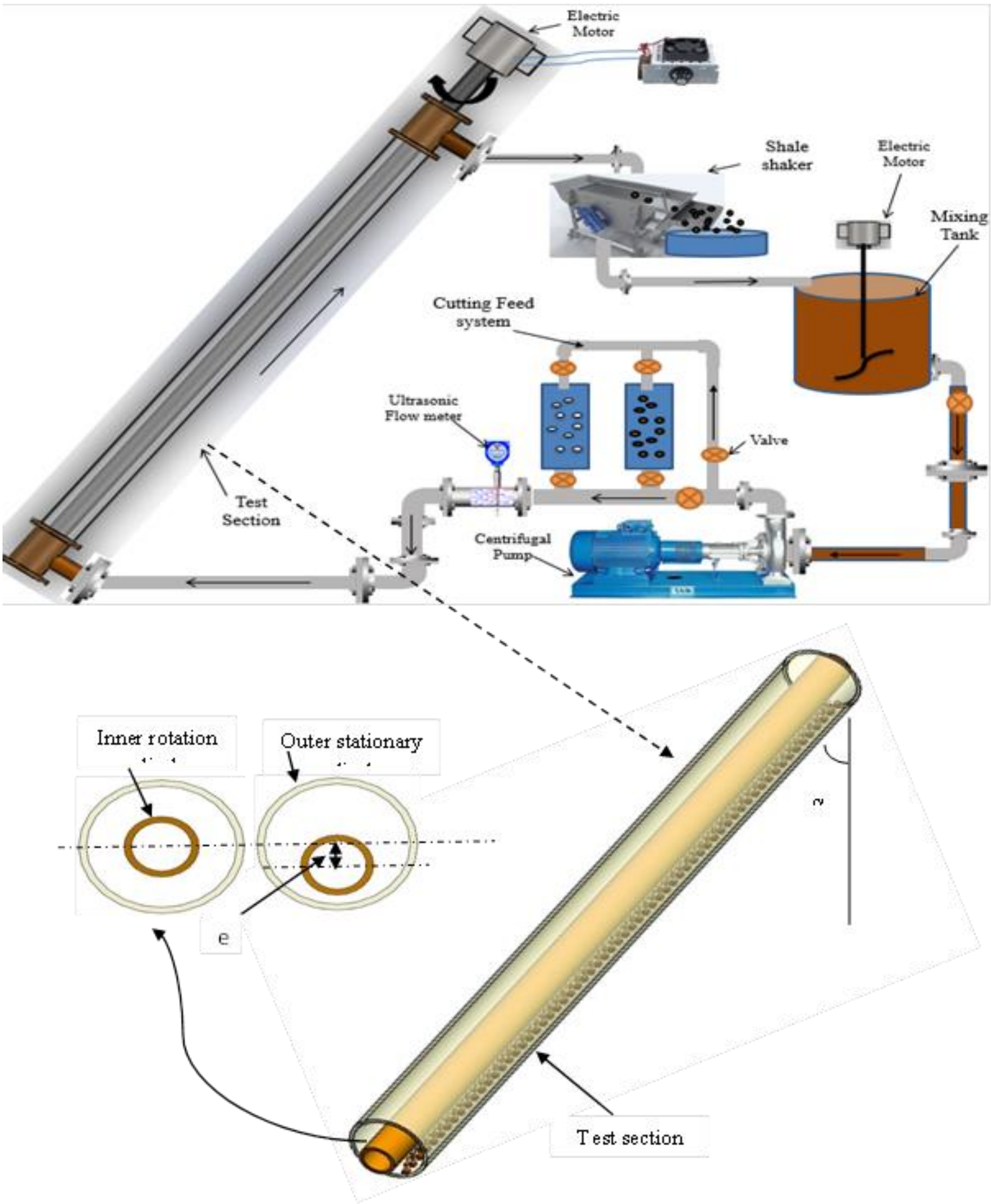

Fig. (1): Base-case flow geometry.

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4. Independent Study of Computational Meshes and Grids.

In all flow configurations, both dynamic and static hexagonal meshes were used. At the inlet and outflow borders, edge scaling and face meshing techniques were used to provide a high resolution capable of recording boundary circumstances. It was critical to maintain a high degree of orthogonally and minimal skewnes in the mesh; hence, the number of exterior pipe divisions was equal to the number of internal pipe divisions. To establish the optimal number of elements required to provide an accurate solution while using the fewest computer resources possible, a grid size independence research was performed on all pipe eccentricities evaluated Figure (2). As seen in Figure (3), the concentric flow arrangement needs more elements than the eccentric annuli to provide an independent solution regardless of the grid size.

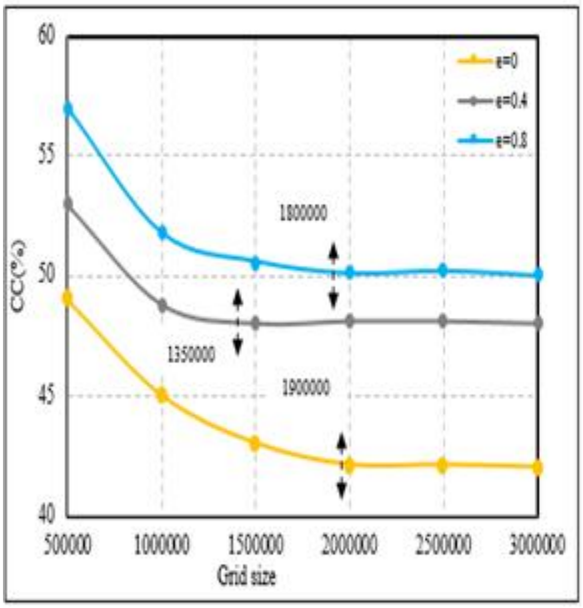

Fig. (2): Sensitively analysis of grid size

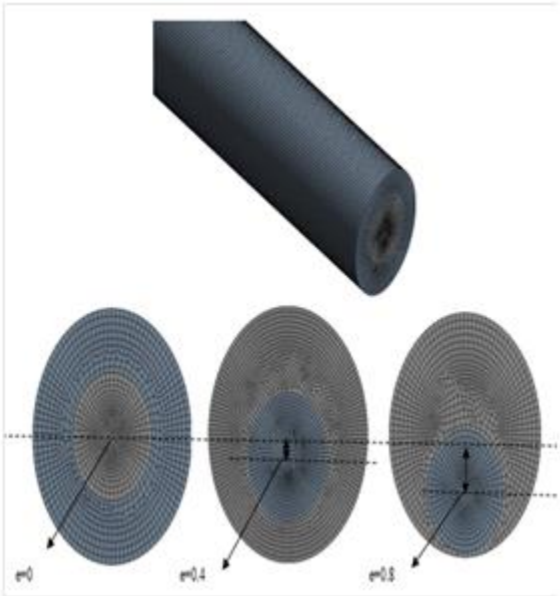

Fig. (3): Mesh generated

5. Boundary Conditions

In this work, the boundary conditions are shown in Figure (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.

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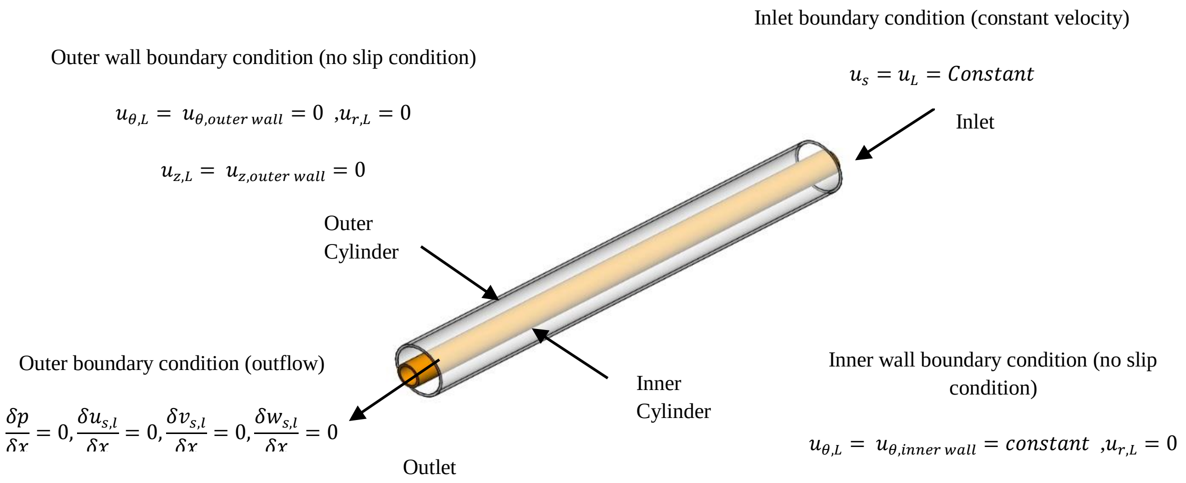

Fig. (4): Boundary condition

6. Study Summarizes

The stages of study that followed to conduct the study begins after completing all of the requirements related to CFD programs that have been clarified in the current study body. The study is summarized by examining the factors that affect the cutting transport represented by (drilling tube rotation, decentralization, drilling pipe incline, fluid temperature, rheological properties and flow rate of the drilling fluid). For the purpose of obtaining a wide range of results, three types of drilling fluids were chosen.

7. Results and Discussion

7.1 Validation the Numerical Model

To reach reliable results, it is important to validate the developed numerical model. For the purpose of verifying the numerical model, the model was rebuilt to accommodate the experimental model studied by the researcher [20]. The conditions under which the model is validated is a choice of viscous liquid (3 MPa) and drilling fluid flow velocity (0.5 m / s) without rotation of the drill pipe. Figure (5) shows a comparison between the practical and theoretical side of the effect of changing the angle of inclination of the drill pipe on the cuttings volumetric concentration (CVC). From the figure, we note that there is a clear convergence in the results with the error rate (7%) due to losses on the practical side and assumptions on the theoretical side.

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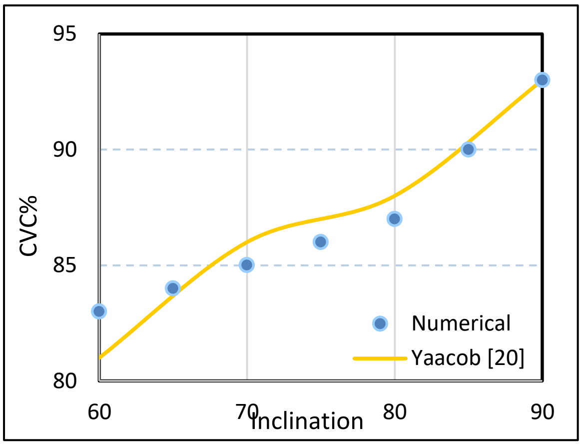

Fig. (5): Comparison between results of present model and that for [20] for the effect of inclination of the drill pipe on the (CVC).

7.2 Numerical Results

The advent of computational fluid dynamics (CFD) and its ability to simulate experimental aspects of numerous studies has provided an unprecedented and unparalleled opportunity to simulate and understand the real complex flows of drilling fluid during drilling operations, especially when the costs of conducting experimental studies in this field become very expensive. Computational fluid dynamics (CFD) can be considered an effective modelling technique that allows tracking multiphase flow phenomena associated with drilling operations with other effects that accompany drilling.

Figure (6) shows the distribution of particle mass concentration (PMC) and cuttings bed thickness within the annular space of the proposed simulation model in the current study under the influence of the change in drilling fluid flow velocity (0.3, 0.6, 0.9, 1.2 m/s) after three minute from the beginning of the flow . The annular flow segment shown in the above figure represents the first meter of the simulation model and includes the following specifications (ϴ: drilling angle 90 degrees (horizontal), Vc: cuttings size (1.5-2) mm, rpm: drill pipe rotation speed 0, e: the eccentricity of the drill pipe from the center of the well is 0, T: drilling fluid temperature 20 ℃).

From the above figure, we noticed that the (PMC) and the thickness of the cuttings bed within the annular space of the simulation model is affected by the change in the velocity of the drilling fluid flow. It also shows an increase in the concentration of cuttings within the lower half of the

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annular space as a result of the impact of the weight of the cuttings, the effect of gravity, and the sliding velocity. On the other hand, it is clear that increasing the flow velocity increases the thrust of the drilling mud, which helps to reduce the impact of the weight of the cuttings and gravity and to exceed the sliding velocity. We noted that the (PMC) and the thickness of the cuttings bed decrease significantly when the flow velocity is 1.2 m/s compared to the lower velocity.

The process of drilling oil wells is accompanied by many effects that are related to the lifting capacity of the cuttings, so it is necessary to study the effect of the flow velocity of the drilling fluid on the lifting capacity of the cuttings in the presence of other effects accompanying the drilling operations. Figures (7) to (11) illustrate the results of the numerical study of the effect of flow velocity on the concentration of cuttings within the annular space of the proposed simulation model with a length of 4 m (the model corresponding to the experimental side) after 10 minutes from the beginning of the flow under the influence of other variables accompanying the drilling process, including (the speed of rotation of the drill pipe, the size of the cuttings, the temperature of the drilling fluid, the drilling angle, the eccentricity of the drill pipe from the center of rotation).

In general, from the above-mentioned forms, we noted that the cuttings concentration (CC) under all other effects decreases as the flow velocity of the drilling mud increases and varies according to the effect accompanying the flow velocity. This can be explained by the fact that increasing the flow velocity of the drilling mud transforms the flow pattern from laminar to turbulent, and the latter is one of the desired flow patterns during the flow that helps to increase the lifting capacity of the cuttings. The reason for this is that the turbulent flow pattern in the annular space generates a velocity distribution close to the flat profile, which prevents the cuttings from falling or sliding downwards, in contrast to the laminar flow pattern in which the shape of the velocity distribution is more severe, allowing the cuttings to slide from the sides. from Figure (7), It can be seen that the cuttings concentration at the flow velocity (0.3 m/s) reaches 64% when the drill pipe rotation speed is (0 rpm), and the cutting concentration decreases by (60,56,53) % with the increase in the drill pipe rotation speed (40, 80,120) rpm respectively at the same flow velocity of the drilling fluid. On the other hand, we noted that the effect of the rotation speed of the drill pipe on the concentration of cuttings decreases when the flow rate of drilling fluid increases. Figure (8) shows the cuttings concentration decreases with the increase in the flow rate and

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increases with the increase in the size of the cuttings. Where we noted that the cuttings concentration when the flow velocity is 0.6 m/s reaches 48 % when the cuttings size is (0.5-1) mm and it reaches (60,57.52) % when the cuttings size is ((3.5-4) ,(2.25-3),(1.5-2)) mm respectively for the same flow velocity. The concentration of the cuttings within the annular space of the simulation model under the influence of the flow velocity of the drilling fluid and its temperature (20, 30, 40, 50) ℃ shown in Figure (9). We noticed that the increase in the temperature of the drilling fluid weakens the ability of the drilling fluid to move the cuttings, and thus we noticed an increase in the concentration of the cuttings within the annular space at all velocity of flow. The increase in temperature affects the general specifications of the drilling fluid, in particular, the density and viscosity, whose values are related to the generation of the hydrostatic pressure necessary to prevent the collapse of the well and the lifting capacity. Therefore, the increase in the temperature of the drilling fluid is accompanied by a decrease in density and viscosity without affecting the specifications of the cuttings, and this is what generates a divergence between the density values of the drilling fluid from the value of the density of the cuttings, so the lifting capacity decreases. Figure (10) shows the change in the drilling angle has a significant impact on the concentration of cuttings within the annular space of the simulation model at all flow rates. Where we noticed when the flow velocity is 1.2 m/s and the drilling angle is 0˚ (vertical well), the cuttings concentration reaches 30 % within the annular space, while the concentration becomes (41,44,54,32) % at the drilling angle (30˚,45˚,60˚,90˚) respectively at the same stated flow velocity. Meaning that the ability of the drilling fluid to lift the cuttings is as large as possible when drilling vertical wells (0˚) and this is due to the fact that the dominant forces affecting the cuttings, which were mentioned earlier, have the least effect due to their lack of decomposition in the direction of the (x,y) axes. Thus, it is less related to the other parameters associated with the process of drilling oil wells. From Figure (11), we noted that the eccentricity of the drill pipe from the center of rotation has a clear effect on the concentration of cuttings within the annular space, in addition to many problems that accompany this eccentricity at all flow velocities of the drilling fluid. This is due to the eccentricity of the drill pipe from the center of rotation in the direction of the lower half of the annular space and the tendency of the cuttings to gather within this area, making this area closed due to the accumulation of cuttings and the eccentricity of the tube that reduces the area of the annular space in the lower part and thus the drilling fluid cannot This accumulation is removed only after

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using other parameters that help solve this problem associated with the eccentricity of the drill pipe.

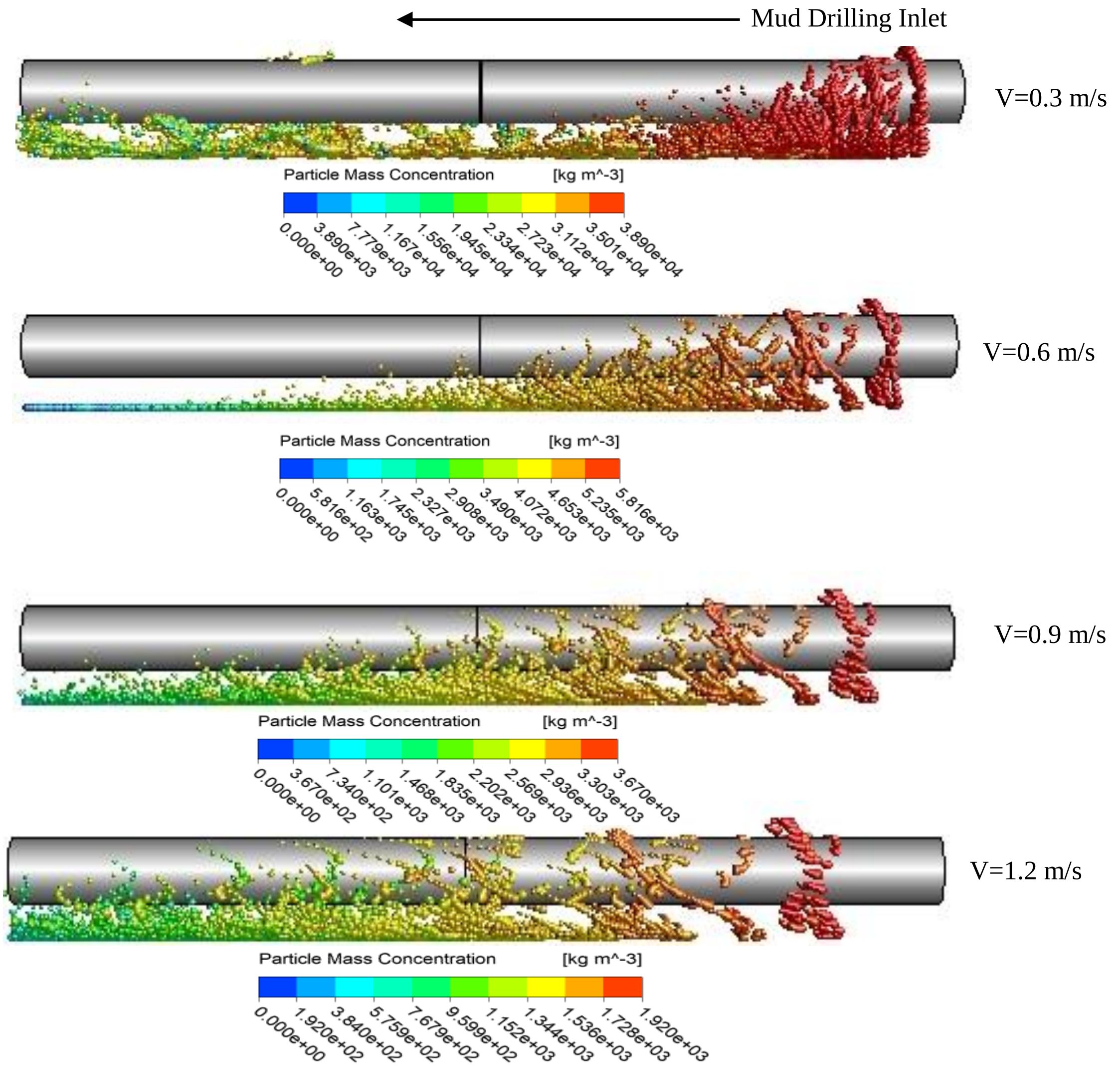

Fig. (6): Distribution of particle mass concentration and cutting bed thickness under the influence of the change in drilling fluid flow velocity (0.3, 0.6, 0.9, 1.2 m/s), (Ө: 90, Vc: (1.5-2) mm, rpm: 0: e=0, T: 20 °C).

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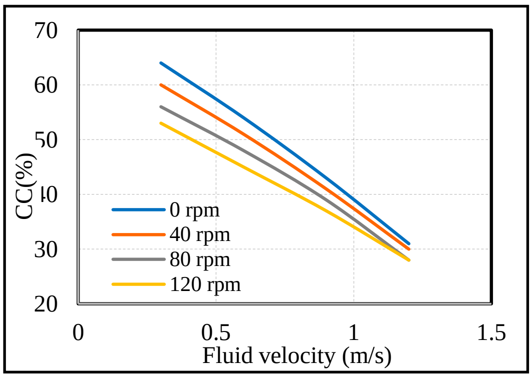

Fig. (7): Effect of the (Vm) on (CC) with drill pipe rotation speed (0, 40, 80,120) rpm (ϴ=0˚, Vc= (0.5-1) mm, e=0, T=20 ℃).

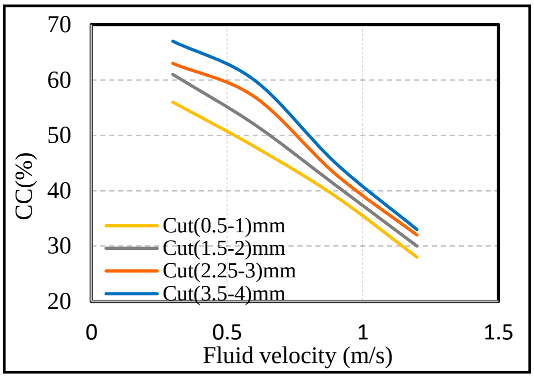

Fig. (8): Effect of the (Vm) on (CC) with cuttings size of ((0.5-1), (1.5-2), (2.25-3), (3.5-4)) mm (ϴ=0˚, rpm=80, e=0, T=20 ℃).

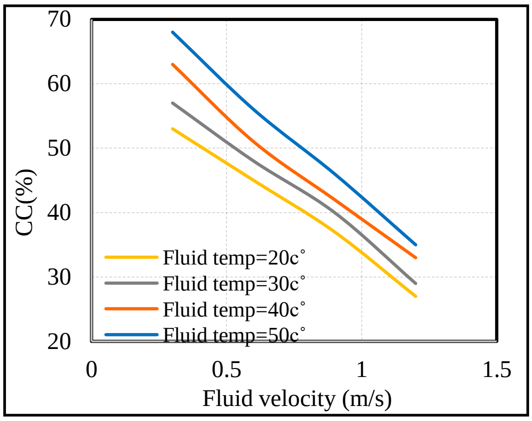

Fig. (9): Effect of the (Vm) on (CC) with drilling fluid temperature (20, 30, 40, 50) ℃ (ϴ=0˚, rpm=120, e=0, Vc = (0.5-1) mm).

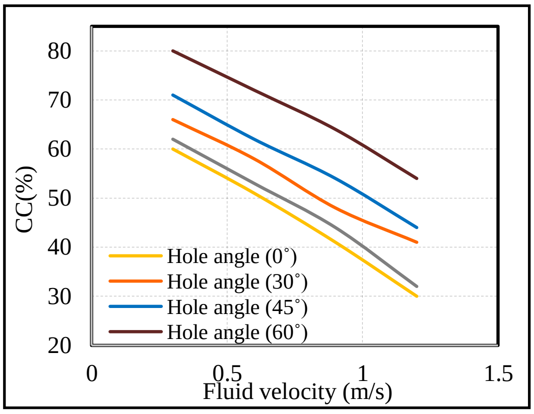

Fig. (10): Effect of the (Vm) on (CC) with hole angle (0˚, 30˚, 45˚, 60˚, 90˚)(Vc= (0.5-1) mm, rpm=40, e=0, T=20℃).

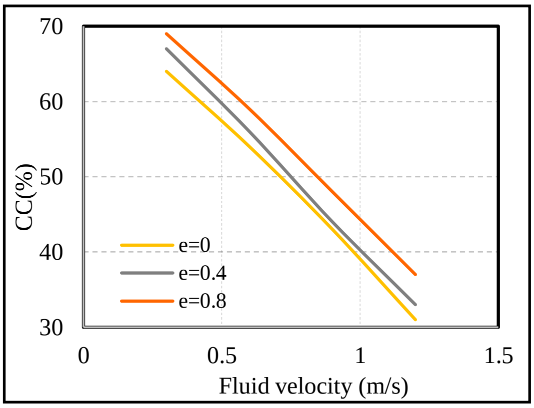

Fig. (11): Effect of the (Vm) on (CC) with (e=0, 0.4, 0.8) (Vc= (0.5-1) mm, rpm=0, ϴ=0˚, T=20℃).

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8. Conclusions

1- There is a clear convergence in the numerical results with experimental studied by the researcher [20] with the error rate (7%). A good agreement was obtained which indicates the reliability and ability of the CFD analysis system to simulate the drilling process.

2- The (PMC) and the thickness of the cuttings bed decrease significantly when the flow velocity is 1.2 m/s compared to the lower velocity.

3- The cuttings concentration (CC) under all other effects decreases as the flow velocity of the drilling mud increases and varies according to the effect accompanying the flow velocity.

4- Increasing the flow velocity of the drilling mud transforms the flow pattern from laminar to turbulent, and the latter is one of the desired flow patterns during the flow that assist to increase the lifting capacity of the cuttings.

5- Cuttings concentration at the flow velocity (0.3 m/s) reaches 64% when the drill pipe rotation speed is (0 rpm), and the cutting concentration decreases by (60,56,53) % with the increase in the drill pipe rotation speed (40, 80,120) rpm respectively at the same flow velocity of the drilling fluid.

6- The effect of the rotation speed of the drill pipe on the concentration of cuttings decreases when the flow rate of drilling fluid increases.

7- Cuttings concentration when the flow velocity is 0.6 m/s reaches 48 % when the cuttings size is (0.5-1) mm and it reaches (60,57.52) % when the cuttings size is ((3.5-4) ,(2.25-3),(1.5-2)) mm respectively for the same flow velocity.

8- The increase in the temperature of the drilling fluid weakened the ability of the drilling fluid to move the cuttings, and thus we noticed an increase in the concentration of the cuttings within the annular space at all velocity of flow.

9- At the flow velocity is 1.2 m/s and the drilling angle is 0˚ (vertical well), the cuttings concentration reaches 30 % within the annular space, while the concentration becomes (41, 44, 54, 32) % at the drilling angle (30˚, 45˚, 60˚, 90˚) respectively at the same stated flow velocity.

10- The eccentricity of the drill pipe from the center of rotation has a clear effect on the concentration of cuttings within the annular space, in addition to many problems that accompany this eccentricity at all flow velocities of the drilling fluid.

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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.

Abbreviation

CFD	Computational Fluid Dynamics.
E-E	Eulerian-Eulerian.
WBM	Water-based mud.
CVC	Cuttings Volumetric Concentration.
CC	Cuttings Concentration.
RPM	Revolutions per Minute.
e	eccentricity.

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