Congrès Français de Mécanique

29 août - 2 septembre 2022 - Nantes

Recueil des Articles

Editorial

Bonjour à tous,

Nous sommes heureux de vous accueillir pour cette 25e édition du Congrès Français de Mécanique (CFM) en 2022. Un grand nombre de scientifiques français et francophones des universités et des entreprises sont attendus pour cette édition.

Après une tentative d'organiser cette conférence 2021 reportée à cause du COVID, nous pouvons enfin nous retrouver. C'est donc avec un grand plaisir que nous vous accueillons à Nantes qui pour la deuxième fois héberge le Congrès Français de Mécanique. La première édition à Nantes était en 1987. Le CFM est un lieu d'échange, de partages entre les chercheurs. Pour favoriser vos échanges, nous avons décidé d'organiser cette édition du CFM à la cité des Congrès de Nantes. Ainsi dans ce lieu unique, vous pourrez échanger soit entre les sessions ou lors des pauses cafés.

Cette édition du CFM est composé de 35 sessions et d'un mini-symposium. Pour la première fois, le Congrès Français de Mécanique offre une session dédiée à la place des femmes en Mécanique. Cette session s'intéressera aux conséquences sur la vie et la carrière des femmes engagée en Mécanique et sur le manque d'appétence des filles pour les Sciences, les Technologies, l'ingénierie et les Mathématiques. Pendant cette 25e édition du CFM, un mini-symposium dédié aux doctorants et jeunes docteurs en Mécanique afin d'informer et d'échanger sur la valorisation du doctorat en Mécanique est organisé. Ce mini-symposium est sous l'égide de l'Association du Réseau des Ecoles Doctorales en Sciences pour l'Ingénieur (REDOC-SPI).

Des cours en amont de la conférence ont été proposés. Quatre cours intitulés " Surfaces immatérielles en mécanique et en physique : description théorique et numérique ", " Méthodes hybrides RANS/LES pour la turbulence: théorie et applications ", " Transport Phenomena in Complex Fluids " et " Génération de maillages - Passé-Présent-Futur " ont été proposés le samedi après-midi et le dimanche matin avant le CFM. Ces cours ont rencontré un véritable succès car 45 étudiants ont suivi ces cours.

Enfin, Nantes présente de nombreux centres d'intérêts. Une façon originale de découvrir la ville est de suivre la ligne verte qui vous permettra de découvrir la ville à travers une multitude de propositions culturelles.

Au nom de l'ensemble du comité d'organisation et du comité scientifique, nous vous souhaitons un excellent congrès.

Emmanuel Guilmineau, Président du comité d'organisation

Nicolas Moës, Président du comité scientifique

Comité scientifique

Nicolas MOES	Centrale Nantes, Président du comité scientifique
Michel VISONNEAU	Centrale Nantes, Coprésident Fluides
Fabien AMIOT	FEMTO-ST
Michel ARRIGONI	ENSTA Bretagne
Jacques-André ASTOLFI	IRENav
Sandrine AUBRUN-SANCHES	Centrale Nantes
Mejdi AZAIEZ	ENSCBP
Françoise BATAILLE	PROMES
Henri BERTIN	I2M
Pierre-Olivier BOUCHARD	Mines ParisTech
Damien CHABLAT	Centrale Nantes
Noël CHALLAMEL	IRDL
François CHARRU	Université Paul Sabatier (Toulouse 3)
Philippe COUSSOT	Univ. Eiffel
Laurent DAVOUST	Grenoble INP
Antoine DAZIN	ENSAM
Stéphanie DEBOEUF	Sorbonne Université
Yannick DESPLANQUES	Centrale Lille
Jean-Luc DION	SupMeca
Jean-François GANGHOFFER	Univ. Lorraine
Olivier HUBERT	Univ. Paris-Saclay
Olivier KIMMOUN	Centrale Marseille
Azeddine KOURTA	Univ. Orléans
Carl LABERGERE	UTT
Olivier LE MAITRE	Ecole Polytechnique
Patrice LONGERE	ISAE SUPAERO
Ahmed LOUKILI	Centrale Nantes
Yann MARCO	ENSTA Bretagne
Jean-Philippe MATAS	Univ. Lyon 1
Katia MOCELLIN	Mines ParisTech
Franck MOREL	ENSAM
Laurent ORGEAS	Univ. Grenoble Alpes
Guillaume POLIDORI	Univ. Reims
Lionel ROUCOULES	ENSAM
David RYCKELYNCK	Mines ParisTech
Laurent STAINIER	Centrale Nantes
Julien YVONNET	Univ. Paris Est

Comité d'organisation

Emmanuel GUILMINEAU	Centrale Nantes/LHEEA, Président
Amine AMMAR	ENSAM Angers
Jacques André ASTOLFI	École Navale
Teodor BURGHELEA	Université de Nantes
Aziz HAMDOUNI	Université de la Rochelle
Steven LE CORRE	Université de Nantes
Elodie LIZE	Centrale Nantes/LHEEA
Sandrine JAMET	Centrale Nantes/LHEEA
Gilles MARCKMANN	Centrale Nantes/GeM
Jeroen WACKERS	Centrale Nantes/LHEEA

Table des Matières

2D model to investigate cuttings transport in deviated well: application to the 10-P HTHP well, Cuu Long Basin, Vietnam

Thi Hai Yen Nguyen[1,2*], **Van Thinh Nguyen**[1], **Sylvain S. Guillou**[2]

[1] Faculty of oil and gas, Hanoi University of Mining and Geology (HUMG), Duc Thang, Bac Tu Liem, Hanoi, Vietnam; nguyenvanthinh@humg.edu.vn; nguyenthihaiyen@humg.edu.vn

[2] Laboratoire Universitaire des Sciences Appliquées de Cherbourg (LUSAC, EA 4253), Normandy University, UNICAEN,60 rue Max Pol Fouchet, CS 20082, 50130 Cherbourg-Octeville, France; thi-hai-yen.nguyen@unicaen.fr ; sylvain.guillou@unicaen.fr (S.S.G.)

* Corresponding author.

Abstract

Cuttings transport investigation is a mandatory demand in petroleum engineering to estimate performance of hole cleaning due to its significant role in ensuring a prosperous drilling operation, especially in the case of deviated well with complex geometry. Thus, we aim to study the removal of cuttings in a horizontal double-curve well with reference to the prospecting HPHT well 10-P located in Cuu Long basin, Viet Nam. The 2D Euler-Euler model is utilised to model the two-phase flow where the drilling mud is considered non-newtonian and the solid phase is treated as a continuous phase. The numerical models are then validated with theoretical Larsen models. Results of the calculation enable us to predict accumulations of cuttings at different sections of the wellbore.

Résumé

Le transport de déblais de forage est un sujet d'étude incontournable pour l'industrie pétrolière, pour évaluer les performances de nettoyage de trou de forage et garantir la bonne marche des opérations de forage, en particulier dans le cas de puits de forage courbes et de géométries complexes. Ainsi nous abordons l'étude de l'enlèvement de déblais de forage dans un puits horizontal à double courbe, avec comme référence le puits de prospection HPHT 10-P situé dans le basin de Cuu Long au Viet Nam. Le modèle 2D Euler-Euler est utilisé pour modéliser l'écoulement diphasique où la boue de forage est considérée comme un fluide non-newtonien et la phase solide considérée comme continue. Les modèles numériques sont alors validés par comparaison aux modèles théoriques de Larsen. Les résultats permettent de prédire l'accumulation de déblais de forage à différentes sections.

Key words: Cuttings transport, HTHP, deviated well, Euler-Euler

1. Introduction

In petroleum drilling, drilling mud play its role as a conduct to transport rock fragments, induced during the penetration of the drill-bit into the earth's crust, upwards to the surface, fig 1.1. A poor hole cleaning performance may cause aggressive accumulation of cuttings at low side of the wellbore, which is considered a root cause of several problems to the drilling operation such as stuck pipe [1],[2],[3] especially in deviated well. The efficiency of the cuttings transport depends greatly on operational parameters such as: mud pump flowrate which decides the annular velocity of the upward flows [14], [15]; rheology the drilling fluid which plays a very important part in removing cuttings, especially in highly inclined and hozional wells [16], [14]; hole inclination which affects the process to evacuate cuttings out of the drilling well [13] and ROP (rate of penetration) and pipe rotation (rpm) which take their effects on the cleaning efficiency by reducing cuttings deposition and preventing the accumulation of the cuttings bed [13], [11], and properties of cuttings. Various numerical and experimental studies have been carried out to estimate effects of influential parameters on the performance of cuttings transport with applications to horizontal, vertical or inlined wells independently. However, very few considered a deviated well trajectory completely. Therefore, we aim in our research to create a two-phase 2D model to investigate the removal of cuttings in a 5-section deviated well. The calculating domain is constructed as a reduced model refering to the well 10-P in Culong Basin, Vietnam. This well is known as a horizontal double-curve well, in which its trajactory composes of 3 major sections including: a) vertical section from spuding, b) inclined part after the first kick-off point and c) approximately horizontal section to reach to the objective reservoir, *figure 1.2*. We expect to obtain a panoramic view of the whole circulating process through this complex domain, that is absent from mostly all research on drill cuttings transport.

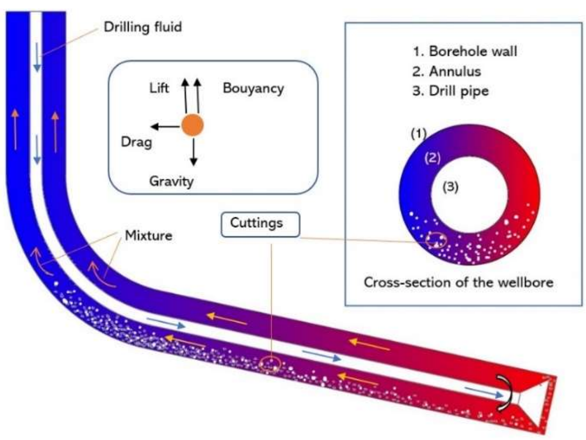

Figure 1.1. Two-fluid flow inside a drilling well

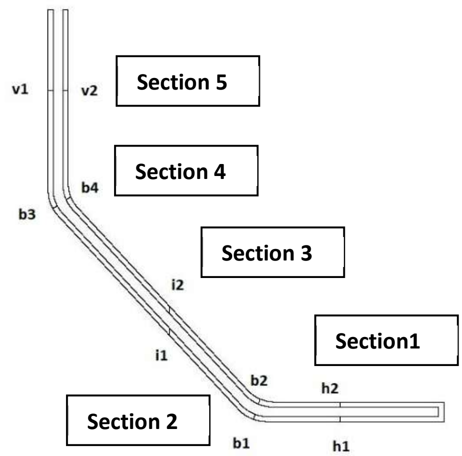

Figure 1.2. Reduced cuttings transport model with reference to the horizontal double-curve well, 10-P

2. Methodology

Gas phase and bubble are neglected in this work, thus, the flow coming upward consists of two phases: drilling mud (fluid phase) and cuttings (solid phase). Where, the drilling fluid is considered as a homogenous water-based mud with no additives added to gain desired rheology. The Euler-Euler (EE) model is adopted to solve this multiphase flow in the interest of saving time [9] while providing trustable results.

According to ANSYS Fluent, mathematical formulations for EE model are written in form of Continuity equation, Fluid-fluid momentum equation and fluid-solid momentum equation:

* Continuity:

$$\frac{1}{\rho_c}\left(\frac{\partial}{\partial t}(\alpha_c\rho_c)+\right)+\nabla.(\alpha_c\rho_c\vec{v}_c) = \sum_{m=1}^{N}(\dot{m}_{mc}-\dot{m}_{cm}) \quad (2.1)$$

* Fluid-fluid momentum equation:

$$\frac{\partial}{\partial t}(\alpha_m\rho_m\vec{v}_m) + \nabla.(\alpha_m\rho_m\vec{v}_m\vec{v}_m) = -\alpha_m \nabla p + \nabla.\bar{\bar{\tau}}_q + \alpha_m\rho_m\vec{g} + \sum_{c=1}^{N}\big(K_{mc}(\vec{v}_m - \vec{v}_c) + \dot{m}_{mc}\vec{v}_{mc} - \dot{m}_{cm}\vec{v}_{mc}) + (\vec{F}_m + \vec{F}_{lift,m} + \vec{F}_{vm,m} + \vec{F}_{td,m})\big) \qquad (2.2)$$

* Fluid – solid momentum equation:

$$\frac{\partial}{\partial t}(\alpha_c\rho_c\vec{v}_c) + \nabla.(\alpha_c\rho_c\vec{v}_c\vec{v}_c) = -\alpha_c \nabla p - \nabla p_s + \nabla.\bar{\bar{\tau}}_q + \alpha_c\rho_c\vec{g} + \sum_{m=1}^{N}\big(K_{mc}(\vec{v}_m - \vec{v}_c) + \dot{m}_{mc}\vec{v}_{mc} - \dot{m}_{cm}\vec{v}_{mc}) + (\vec{F}_c + \vec{F}_{lift,c} + \vec{F}_{vm,c} + \vec{F}_{td,c})\big) \qquad (2.3)$$

Where, $\vec{v}_m$ and $\vec{v}_c$ are velocity of the drilling mud (fluid phase) and cuttings (solid phase) respectively; ρ_m and ρ_c are densities of the two phases.

The flows are expected to be turbulent, thus, the k-e viscous model is activated. The well 10-P is drilled in high pressure, high temperature (HPHT), ie., T ~ 150 ÷ 205°C and P ~ 10.000 ÷ 20.000 psi). To consider these features, the mud flow is treated as non-Newtonian fluid. Fluent enables us to approximately characterize the fluid phase as non-Newtonian fluid by using power-law (PL) rheology model, Herschel-Bulkley or Carreau model [12,13]. For the sake of simplicity, PL model is utilised.

Using EE approach, particle phase is regarded as continous phase and set as granular flow which obeys the granular viscosity model suggested by Syamlal et al, 1993. An estimation of the particles injection velocity has been made basing on the penetration rate (ROP). The experimental Larsen model [5],[6],[7],[8],[10], which describes relation between cutting velocity Vc and the rate of penetration ROP as in the equation (Eq.(2.4)), is employed to validate numerical results.

$$V_c = \frac{ROP}{36\left[1-\left(\frac{D_p}{D_h}\right)^2\right]C_c} \qquad (2.4)$$

Where, D_p represents diameter of cuttings, D_h is the diameter of the borehole, C_c is the concentration factor of cuttings.

Calculation data is recapitulated in the following table, *table 1*.

Table 1. Calculation data

Parameters	**Testing values**
Diameter of drillpipe, D_p, m	0.2
Diameter of wellbore, D_h, m	0.4
Distance between wellbore and drillpipe, r_i, m	[0:0.15]
Mud density, rho (γ), kg/m^3	1010; 1050; 1200;1300
Velocity of mud, V_f, m/s	0.04;0.08; 0.2; 0.4; 0.8; 1.0
Cuttings density, kg/m^3	2600
Cuttings dimension, D_c, m	0.001; 0.005;0.01
Cuttings velocity, V_c, m/s	0.008
Temperature, °C	150
Pressure, psi	12000
Turbulent intensity	8%

As can be seen in the table, quantities of cuttings size, velocity of the drilling fluid and mud density vary respectively each by each in different test cases. The set of values, V_f = 0.4 m/s; D_c = 0.001m; V_c = 0.08 m/s, γ = 1010 kg/m^3 is taken as reference data (the same values as data measured at the actual well 10-P).

3. Results

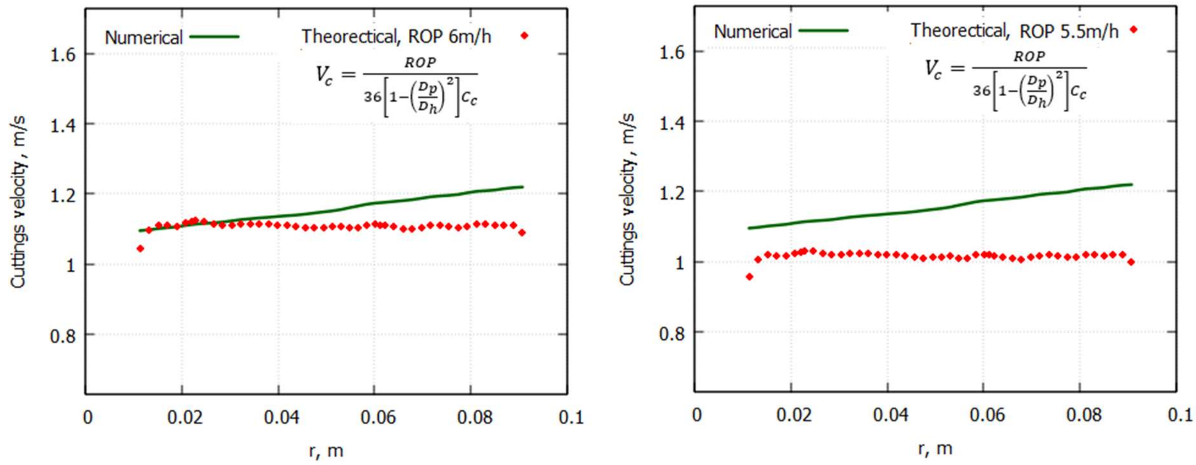

Figure 3.1. Theoretical vs numerical cuttings velocity, ROP = 5.5 and 6.0m/s (section 2)

Preliminary calculations were first carried out using reference data. The numerical cuttings velocity is presented in figure 1 in comparison with cuttings velocity, V_c, calculated from eq. (2.4). As observed, numerical model shows a tendency to increase the magnitude of cuttings velocity, especially in the case of lower ROP. However, the result is considered acceptable due to the difference in geometry between our calculating domain and the actual well. Thus, the model is used for further calculations. In the current research, two cases of simulation were carried out to investigate dependency of cuttings transport on cuttings size and velocity of the drilling fluid.

Results of calculations are extracted for the two branches of the domain from the bottom to the top as denoted in *figure 1.2*. We consider all 5 sections thoughout the calculating domain, two lines at each. *Section 1* with h1 and h2, is the horizontal part; *section 2* consists of bend 1 (b1) and bend 2 (b2); *section 3* is the inclined part with i1 and i2 at each branch; *section 4* composes of the two other bends b3 and b4; and *section 5* with v1 and v2 is vertical section. Length of each line equals r_i max = 0.1m corresponding to the distance between the borehole wall and the drillpipe as the well is concentric.

* *Study case 1: Dependence of cuttings velocity on cuttings size*

Figure 3.2, 3.3 demonstrates the relation between cuttings size on the transportation of cuttings with the red curve represents velocity of cuttings at the suspension layer and the other in black depicts velocity at the dispersed layer. As observed, cuttings velocity decreases sharply with the increase of cuttings mass and size at all the 5 sections. The higher the size of particle, the smaller the velocity of cuttings, especially at dispersed layer and as a consequence the faster the settelling of cuttings and the thicker the cuttings bed. V_c drops to very small values when D_c = 0.01m that enables us to predict a blockage if V_f remains unchanged. However, compare to results published by Shu, 2021, our model seems to overestimate magnitude of velocity in the annulus [16]. In figure 3.3, the concentration of cuttings of different size at 5 different sections is illustrated. As observed, the highest accumulation of cuttings corresponds to the case D_c = 0.005mm, not to the case of cuttings with largest diameter Dc = 0.01m. This seems to be a paradox at first, however, it's quite logic due to a confirmation that larger cuttings size benefits a higher removal than those of smaller size [17].

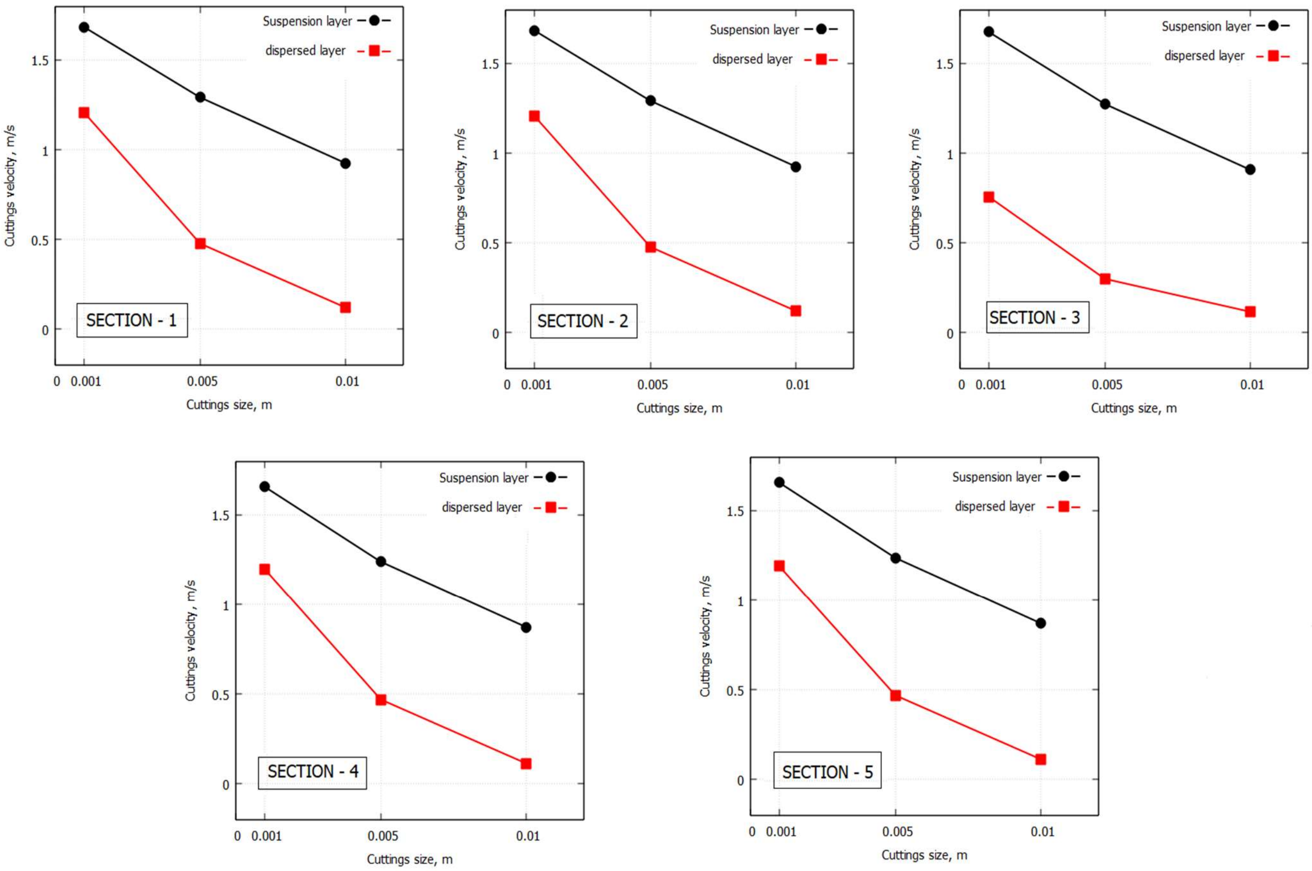

Figure 3.2. Effect of cuttings size D_c on cuttings velocity V_c at 5 sections (V_f at the inlet takes the reference value, $V_f = 0.4$)

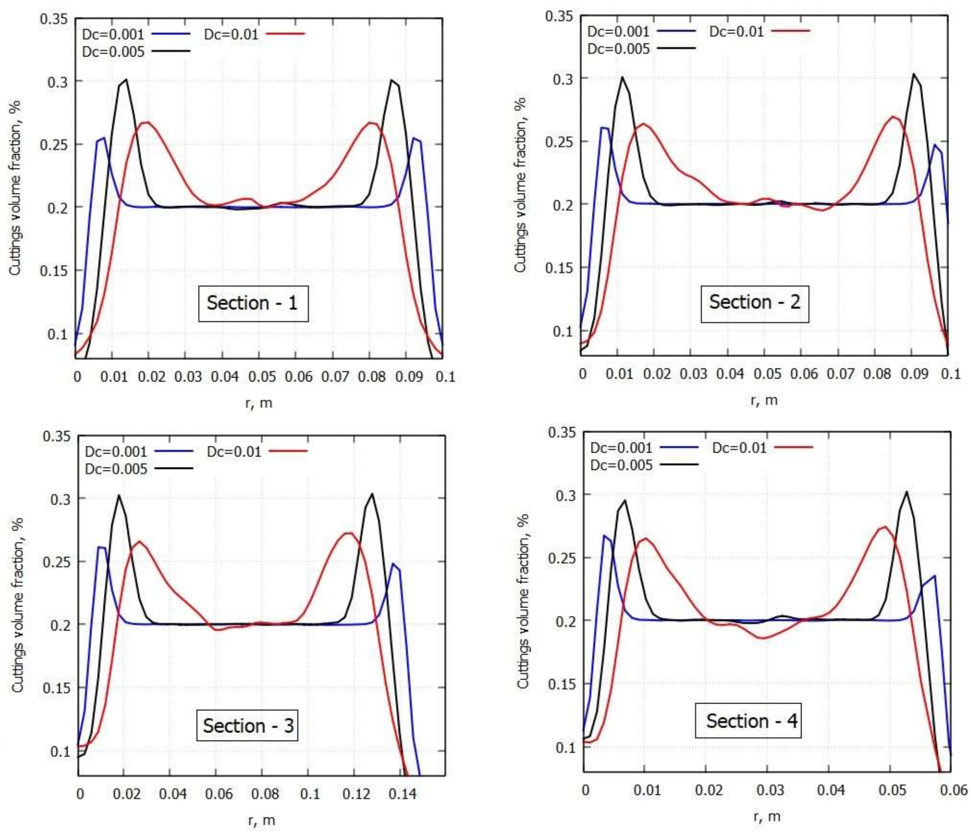

Fig 3.3. Volume fraction of cuttings for different sizes of cuttings, Dc

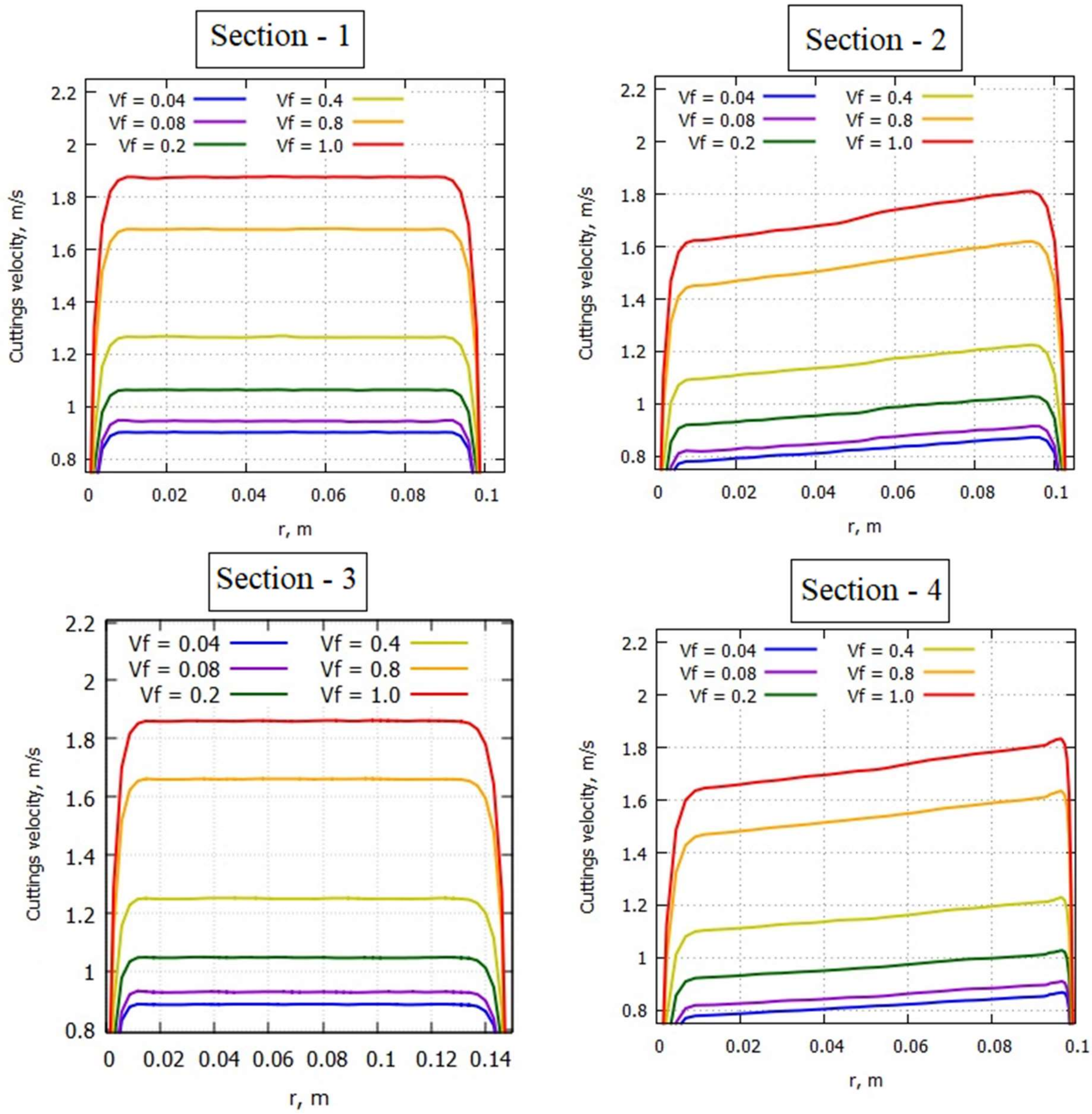

Figure 3.4. Cuttings velocity at different mud speeds

** Study Case 2: Impact of mud velocity on the transportation of cuttings at different sections of the wellbore*

Figure 3.4 illustrates cuttings velocity at 5 different sections. Velocity curves seem to be flat and smooth around the centre of the pipe, whereas slight fluctuations are observed at the contact areas between the flow and the borehole wall and the pipe. At the two bends (section-2 and section-4), V_c tends to be smaller and linearly increases following the direction from the wellbore to its centre. This enables us to confirm a higher risk of cuttings accumulations at the lower sides of the two bends. Besides, it's a doddle to see that higher drilling mud velocity results in higher cuttings velocity. However, a too fast upcoming flow may not be a wise choice due to its capability to cause unstable conditions to the wellbore and formation. Therefore, further calculations should be implemented in order to determine the optimum flowrate to pump down the drilling must obtain maximum hole cleaning performance.

4. Discussion and Conclusion

In this work, 2-dimentional approach using E-E model was carried out to investigate a two-phase liquid-solid (drilling fluid as non-newtonian fluid and cuttings) flow in the annulus. Results show an increase of cuttings concentration at bends in comparison to the other positions of the well. Besides, it confirms a more effective removal with larger cuttings size. Despite of some vauluable insight, the researched domain is scketched with two separated parts which leads to no connection between the upper and lower part of the domain accept at the bottom. While in fact, drilling fluid and cuttings move upward in the annulus, a void formed when a pipe is positioned inside a bigger one. Consequently, 2D model may overevaluate velocities of the flows at each branch of the domain. Besides, rotary movement (RPM) of the drillpipe was neglected due to asymetric geometry of the domain which is the biggest minus of the work. Therefore, 3D models are suggested for later calculations to capture 3 dimentional effects and to consider drilling parameters eliminated in the current research.

References:

[1] Caenn, Ryen, Henry CH Darley, and George R. Gray. *Composition and properties of drilling and completion fluids*. Gulf professional publishing, 2011.

[2] Wastu, A. R. R., Abdul Hamid, and S. Samsol. "*The effect of drilling mud on hole cleaning in oil and gas industry.*" Journal of Physics: Conference Series. Vol. 1402. No. 2. IOP Publishing, 2019.

[3] Epelle, Emmanuel I., and Dimitrios I. Gerogiorgis. "*Drill cuttings transport and deposition in complex annular geometries of deviated oil and gas wells: A multiphase flow analysis of positional variability*." Chemical Engineering Research and Design 151 (2019): 214-230.

[4] Wang, Fuhua, et al. "*High temperature and high pressure rheological properties of high-density water-based drilling fluids for deep wells*." Petroleum Science 9.3 (2012): 354-362.

[5] Hemphill, Terry, and T. I. Larsen. "*Hole-cleaning capabilities of water-and oil-based drilling fluids: a comparative experimental study*." SPE Drilling & Completion 11.04 (1996): 201-207.

[6] Mohammadsalehi, Mehdi, and Nozar Malekzadeh. "*Optimization of hole cleaning and cutting removal in vertical, deviated and horizontal wells*." SPE Asia Pacific Oil and Gas Conference and Exhibition. OnePetro, 2011.

[7] Mohammadsalehi, Mehdi, and N. Malekzadah. "*Application of new hole cleaning optimization method within all ranges of hole inclinations*." IPTC 2012: International Petroleum Technology Conference. European Association of Geoscientists & Engineers, 2012.

[8] Ranjbar, Roozbeh. *Cuttings transport in inclined and horizontal wellbore. MS thesis*. University of Stavanger, Norway, 2010.

[9] Manjula, E. V. P. J., et al. "*A review of CFD modelling studies on pneumatic conveying and challenges in modelling offshore drill cuttings transport*." Powder Technology 305 (2017): 782-793.

[10] Larsen, Thor Inge F. "*A study of the critical fluid velocity in cuttings transport for inclined wellbores*". Diss. University of Tulsa, 1990.

[11] Larsen, T. I., A. A. Pilehvari, and J. J. Azar. "*Development of a new cuttings-transport model for high-angle wellbores including horizontal wells*." SPE Drilling & Completion 12.02 (1997): 129-136.

[12] Wu, Wei-Tao, et al. "*Heat transfer in a drilling fluid with geothermal applications*." Energies 10.9 (2017): 1349.

[13] Tomren, P. H., Iyoho, A. W., & Azar, J. J. (1986). Experimental study of cuttings transport in directional wells. *SPE Drilling Engineering*, *1*(01), 43-56.

[14] Al-Azani, K., Elkatatny, S., Ali, A., Ramadan, E., & Abdulraheem, A. (2019). Cutting concentration prediction in horizontal and deviated wells using artificial intelligence techniques. *Journal of Petroleum Exploration and Production Technology*, *9*(4), 2769-2779.

[15] PIROOZIAN, Ali, ISMAIL, Issham, YAACOB, Zulkefli, *et al.* 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*, 2012, vol. 2, no 3, p. 149-156.

[16] Zhu, X., Shen, K., & Li, B. (2021). Investigation: Cutting Transport Mechanism in Inclined Well Section under Pulsed Drilling Fluid Action. *Energies*, *14*(8), 2141.

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