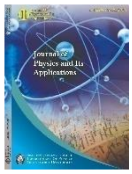
Journal of Physics and Its Applications

Journal homepage: https://ejournal2.undip.ac.id/index.php/jpa/index



Fluid Flow Regimes Analysis on Drilling Fluid Circulation for Cuttings Lifting in Vertical Drilling Oil Wells

Isnani Agriandita*[1], Ismanu Yudiantoro[1], and Niken Ayoba[2]

[1]*Department of Diploma Petroleum Engineering, Institut Teknologi Petroleum Balongan, Indramayu, Indonesia*
[2]*Department of Diploma Petroleum Engineering, Akademi Minyak dan Gas Balongan, Indramayu, Indonesia*

Corresponding author: isnaniee@gmail.com

A R T I C L E I N F O

Article history:
Received: 20 January 2023
Accepted: 11 April 2023
Available online: 31 May 2023

Keywords:
Fluid Flow
velocity
Reynolds Number
Turbulent
Laminar

A B S T R A C T

Fluid Flow during the circulation of the drilling fluid is an important parameter that affects the process of successful lifting of cuttings during drilling activities. Researcher analyzed the regimes of the drilling fluid flow in vertical drilling wells through the analysis of the velocity calculation of the drilling fluid in the pipeline at conditions in the Drillpipe (v DP) of 21.11791 fps and in drill collar of (v DC) is 42.98293 fps, the velocity of drilling fluid in the annulus between the Casing and the Drill pipe is 1.14993 fps, 1.373781 fps between Open Hole and Drill pipe, and 1.594947 fps between Open Hole and Drill Collar, the critical velocity of drilling fluid in the pipeline and in the annulus, Reynolds number in the pipeline is 15986.36, inside Drill Collar of 22807.21, and in the annular between the Casing and the Drill pipe is 2847.435, between Open Hole and Drill pipe 3037.264, and 2679.938 between Open Hole and Drill Collar, and the velocity at which the drill cutting drops when in the annulus in all three zones is 0.14914 fps. The results of the analysis of fluid flow that occurs are found that in the pipe there is a turbulent flow and in the annulus a laminar flow occurs. In addition, the results of the analysis of the comparison between the velocity of the drilling fluid in the annulus and greater than the velocity of descent of the cuttings show that the cuttings can be lifted by the drilling fluid successfully. This indicates that the fluid lifting process is successful.

1. Introduction

The circulation of the drilling fluid greatly affects the process of removing the cuttings. The proper drilling fluid circulation process can provide maximum well hole cleaning and can minimize the presence of other problems such as the entry of drilling fluid into the formation.

The cuttings resulting from grinding by the drill bit will tend to be piled up at the bottom of the well hole during drilling, therefore the drilling fluid circulation process is carried out to lift the cuttings to the surface. The velocity of the drilling fluid circulated into the well hole is one of the parameters that is very important for determining the success of the cuttings lifting process[1]–[3].

When the fluid circulation process takes place, it is arranged in such a large way as the flow rate of the drilling fluid. The selection of this fluid flow rate will affect the magnitude of the velocity of the drilling fluid to be able to lift the cuttings to the surface. Two velocities need to be considered for the success of the cuttings lifting process, namely the annular velocity and the velocity at which the cuttings drop to the bottom at the time the lifting is carried out. Analysis of the annular velocity and the velocity at which the cuttings drop will be obtained whether the drilling fluid circulated into the well hole during drilling activities can lift the cuttings [4], [5].

Annular velocity is the velocity of the drilling fluid within the annulus which is controlled by the pumping rate. When the velocity of the drilling fluid in the annulus is greater than the critical velocity of the drilling fluid in the annulus then the form of fluid flow that occurs is a turbulent flow, if the velocity of the fluid flow in the annulus is smaller than the critical velocity of the fluid in the annulus then the flow form is laminar [6]. The regime of this flow can express how much pressure loss occurs. In addition, the regime of the fluid flow in the annular affects the value of the velocity at which the cuttings drop [7].

Drilling mud is one of the most important parts of the successful drilling process in the oil and gas field. Therefore, the rheology and physical properties of the drilling mud need to be considered in the drilling process. Some of the rheology and physical properties of drilling mud are the density of the drilling fluid, the regime of the flow, the size of the annulus velocity of the drilling fluid. In addition, some of the properties of cutting also need to be considered, namely the density of cutting and the regime of the cutting, as well as the velocity at which the cuttings drop [4], [8], [9]. Drilling mud fluid belongs to the non-Newtonian fluid type, namely the Bingham Pseudoplastic [10], [11].

The fluid flow velocity is obtained by flowrate of the fluid ($m^3/_s$) divided by the cross-sectional area of the flow (m^2) [10]:

$$v = \frac{Q}{A} \quad (1)$$

From the Equation (1) hence the flow velocity of the drilling fluid ($^{ft}/_s$) or fps inside the drilling pipe with a fluid flowrate (gpm) and drill pipe diameter (inch) become [10], [12]:

$$v = \frac{Q}{2.448 \times dp^2} \quad (2)$$

The flow velocity of the drilling fluid in the annulus (fpm) is influenced by the pumping rate (gpm) and the diameter of the annular cross section through which the drilling fluid (inch) travels [10].

$$v_a = \frac{24.48 \times Q}{D_2^2 - D_1^2} \quad (3)$$

The form of drilling fluid flow in the form of laminar or turbulent is obtained by looking at the average velocity of fluid flow in the annulus with the critical velocity of fluid flow in the annulus. If the average velocity of fluid flow in the annular is smaller than its critical velocity then the form of flow is laminar [1]. If the average velocity of fluid flow in the annulus is greater than its critical velocity in the annulus then the form of flow is turbulent [1], [6], [10]:

$$v_c = \frac{1.08 + 1.08\sqrt{[PV^2 + \rho(9.26Dh - ODstring)YP]}}{\rho(Dh - ODstring)} \quad (4)$$

In addition, the slip velocity of cuttings also affects the success of cleaning well holes against cuttings. The velocity at which the cuttings falls (Vs) is explained through the stokes law expressing the velocity of deposition or terminal velocity (Vt) of an object that is in diameter d_c and density ρ_s in a fluid medium with density ρ_f and fluid viscosity μ which can be written mathematical equations as follows [7]:

$$V_t(^m/_s) = \frac{d_c^2(m) g(^m/_{s^2})(\rho_s - \rho_f)(^{kg}/_{m^3})}{6\pi\mu(^{kg}/_{ms})} \quad (5)$$

In the well hole cleaning process, the slip velocity of the cuttings has different similarities depending on the regime of fluid flow [6], [13]. In equation (5) by converting the unit of terminal velocity to feet per minute (fpm), the unit of density to pounds per gallon (ppg), the diameter to inch, then the slip velocity of the cuttings becomes:

The velocity at which the cuttings drop on the laminar flow [4]:

$$Vs = 174.7 \frac{dc \times (\rho_c - \rho_f)^{0.667}}{{\rho_f}^{0.333} \times {\mu_e}^{0.333}} \quad (6)$$

The velocity at which the cuttings drop on turbulent streams [10]:

$$V_s = 113.4 \left[\frac{dc(\rho_c - \rho_f)}{1.5 \times \rho_f}\right]^{0.5} \quad (7)$$

The drilling process is said to be successful if the cuttings can be lifted to the surface. Therefore, the velocity of the drilling fluid in the annular must be greater than the velocity at which the cuttings falls, so that the velocity at which the cutting rises is obtained from the following equation [6], [12], [14]:

$$VL = Va - Vs \quad (8)$$

Miscellaneous Fluid Flows

Fluid flow based on the forces acting on the fluid is divided into laminar flow, transition flow, and turbulent flow. In general, the forms of fluid flow that occur in drilling activities are laminar, turbulent, and transitional. In laminar flow, fluid flow appears to move straight. In a Turbulent flow, a fluid flow moves randomly, and a transitional flow is a fluid flow whose flow forms between laminar and turbulent flows.

The laminar flow inside the annular hole moves the cutting over the surface and prevents erosion within the borehole. Turbulent flow occurs at the bottom of the borehole to lift the cutting from the bottom of the borehole [15].

The Reynolds number is the main parameter for determining the regime of the fluid flow. If the Reynolds number is less than 2100 then the fluid flow formation is laminar. If the Reynolds number is greater than 4000 then the fluid flow formation is turbulent. Between the values of 2100 and 4000, the Reynolds number indicates that the fluid is a transitional form [10][15], [16].

For the fluid flow regime on the annulus the value of the Reynolds number can be determined by the following equation [10][15]:

$$N_{Re} = 757 \times \frac{\rho v(d_2 - d_1)}{\mu} \quad (9)$$

Where ρ is the density of the drilling fluid (ppg), va is the velocity of the fluid in the annulus (fps), d_1 and d_2 are the diameter (inch), and μ is the viscosity of the fluid (cp).

2. Methods

This study used data on vertical drilling wells of the 17 ½" Trajectory which can be seen in table 1, Table 2, and Table 3. From this data, data processing is carried out by performing calculations as shown in the flow chart of the research methodology Fig 1.

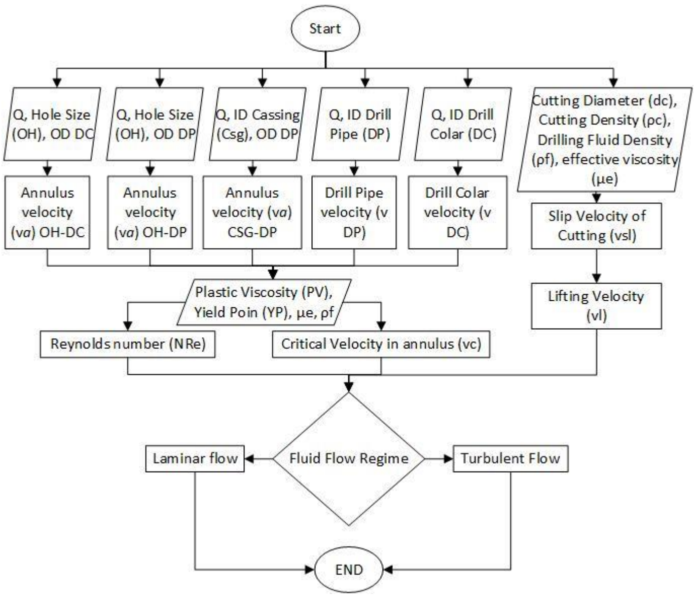


Fig 1. Research Methodology Flowchart.

Table 1. Drilling Fluid Parameter on 17 ½" Trajectory.

Parameter	Value	Unit
Flow Rate	947	GPM
MW	1.15	Sg
PV	26	cps
μ*a*	41	cps
YP	30	lb/100 ft2

Table 2. Drilling Well Hole Specification Data 17 ½" Trajectory.

Parameter	Value	Unit
Bit Size	17.5	inch
Casing (CSG)		
Outside Diameter (OD)	20	inch
Inside Diameter (ID)	19	inch
Length	400	m
Drill Pipe		
OD	5	inch
ID	4.28	inch
Drill Collar		
OD	8	inch
ID	3	inch
DEPTH of Well	810	m

Table 3. Trajectory of Drilling Well Cuttings Specification Data 17 ½".

Parameter	Value	Unit
Cutting Diameter (ds)	0.08	inch
Cutting Density (ρ_s)	2.23	Sg
Cutting Weight	5.35	gram

The results of data processing in the form of Reynolds number and velocities will be used for fluid flow analysis at three annular intervals and in the drilling pipeline. The results of the calculation of velocity and Reynold number show the regime of the fluid flow that can support the success of the cuttings lifting process in the drilling process. Fluid movement in the annulus is laminar to move the cuttings over the surface, fluid movement in the annulus is turbulent to clean the drilling well hole from cuttings in the drilling process [2], [15].

This research is focused on the study of the successful lifting of cuttings in vertical drilling wells of route of drilling fluid in 17 ½" trajectory which can be seen in Fig 2.

The 17 ½" Trajectory of vertical drilling well is a drilling well with a depth of 810 m. From the depth, it can be seen that this drilling activity is carried out at an intermediate depth with a 20" casing is a regime of intermediate casing. In this study, it was assumed that a well with a Trajectory of 17 ½" was in one inhomogeneous rock formation and it has three layers of rock formation.

Fluid flow analysis in the cuttings lifting process is carried out in 5 positions, namely in the Drill Pipe (DP), Drill Collar (DC), Annular Bit, Open Hole (OH) with DC, and OH with DP.

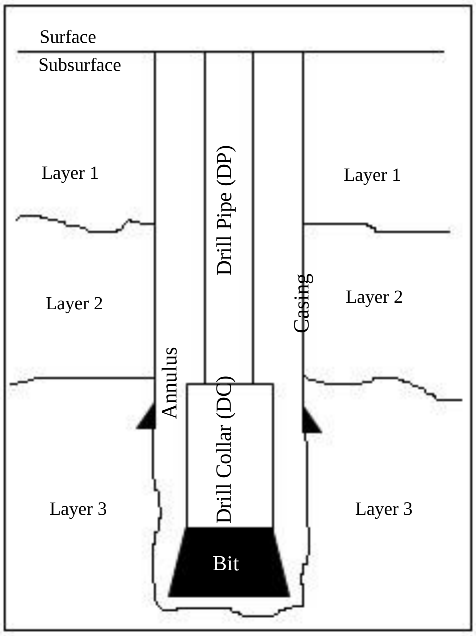


Fig 2. The Scheme of Vertical Drilling Well Profile in 17 ½" Trajectory.

4. Results and Discussion

The lifting of cuttings in the drilling process is very important to pay attention to, this is because if the cuttings lifting process is not successful, it will cause several drilling problems, one of which is the pinching of the drilling tool in the borehole or commonly called pipe sticking.

One of the parameters that affects the success of cuttings is velocity. Through velocity, it can be known the regime of fluid flow that is circulated into the drilling well hole. Cuttings in the drilling process that cannot be lifted will cause the deposit of cuttings in the drilling well hole. Therefore, the turbulent fluid flow regime is the regime of flow that is expected when mud comes out of the drill hole. While the laminar flow regime is the regime of flow expected in the annulus to lift the cuttings above the surface through a circulating drilling mud fluid (see Tables 4 and 5).

Table 4. Results of Calculation of Drilling Fluid Flow Velocity and Reynolds number In Pipe.

No.	Parameter	Result	Flow Regime
1	v DP (fps)	21,11791	Turbulent
	NRe DP	15986,36	
2	v DC (fps)	42,98293	Turbulent
	NRe DC	22807,21	

Table 5. Results of the Calculation of the Flow Rate of the Drilling Fluid in the annulus, the critical velocity of the fluid flow in the Annulus, and the Reynolds number in the Annulus.

No.	Parameter	Result	Flow Regime
1	v_a CSG-DP (fps)	1,14993	Laminar
	NRe CSG-DP	2847,435	
	v_c CSG-DP	1,792924	
2	v_a OH-DP (fps)	1,373781	Laminar
	NRe OH-DP	3037,264	
	v_c OH-DP	1,939432	
3	v_a OH-DC (fps)	1,594947	Laminar

NRe OH-DC	2679,938
v_c OH-DC	2,508877

Table 4 and table 5 show that the flow of drilling fluid inside the pipe is turbulent flow because the Reynolds number is greater than 3000 [10], [16]. In the annulus the flow of the drilling fluid is laminar, this is because the Reynolds number is smaller than 3000 and the critical velocity is greater than the velocity of the fluid in the annulus in the three zones, namely the casing zone with the drill pipe, the open hole zone with the drill pipe, and the open hole zone with the drill collar. The regime of the drilling fluid flow can be seen in the vertical drilling well profile of the 17 ½" Trajectory (Fig 3).

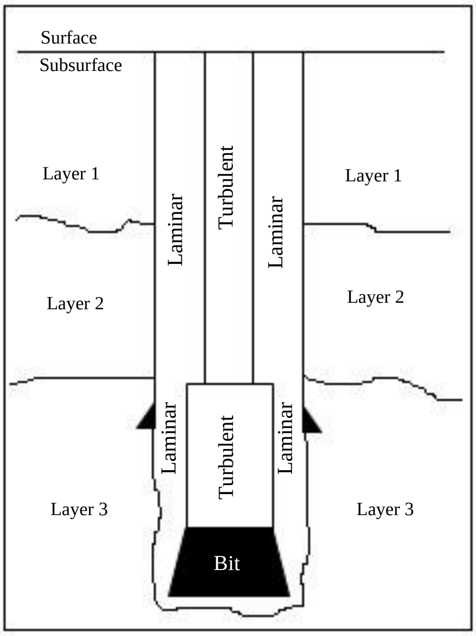


Fig 3. Regimes of The Fluid Flow in Vertical Drilling Well Profile in 17 ½" Trajectory.

In the results that have been obtained in this study, it was found that the fluid flow regime in the pipe is turbulent, this is because the flow rate capacity of the drilling fluid on the pump is made high so that when it comes out of the bit, the flow can remain turbulent to be able to lift the cuttings at the bottom of the well.

In the cuttings lifting process, the cuttings will be lifted above the surface along with the circulation of the drilling fluid flow. Lifting of cuttings over the surface through the open hole zone and cased hole zone. In the cased hole zone, the fluid flow regime is expected to be laminar, this is because the open hole has a thin membrane as a protector called mud-cake. In order for such useful membranes not to be eroded by the flow of drilling fluids, the flow regime must be tried to remain laminar. In the cased hole zone, the flow regime of the drilling fluid must also be maintained laminar to reduce the erosion of the casing wall in the well hole.

In addition to the flow regime of the drilling fluid, the slip velocity of the cuttings is also one of the parameters used to determine whether the cuttings lifting process is successful or not. If the slip velocity of the cuttings is smaller than the velocity of the drilling fluid in the annulus (va) then the cuttings can be lifted so as to allow the cuttings lifting process to be successful (Table 6).

Table 6. Results of Comparison of Cuttings Slip Velocity (vsl) with Lifting Velocity of cuttings (vl) in Annulus.

No.	Parameter	Result	Flow Regime
1	vsl CSG-DP (fps)	0.14914	Laminar
	v_a CSG-DP (fps)	1.14993	
	vl CSG-DP	1.00079	
2	vsl OH-DP (fps)	0.14914	Laminar
	v_a OH-DP (fps)	1.373781	
	vl OH-DP	1.22464049	
3	vsl OH-DC (fps)	0.14914	Laminar
	v_a OH-DC (fps)	1.594947	
	vl OH-DC	1.44580653	

5. Conclusion

Researcher analyzed the regimes of the drilling fluid flow in vertical drilling wells through the analysis of the calculation of the velocity of the drilling fluid in the pipeline at conditions in the Drill pipe of 21.11791 fps and in drill collar of 42.98293 fps, the velocity of drilling fluid in the annulus between the Casing and the Drill pipe is 1.14993 fps, 1.373781 fps between Open Hole and Drill pipe, and 1.594947 fps between Open Hole and Drill Collar, the critical velocity of drilling fluid in the pipeline and in the annulus, Reynolds number in the pipeline is 15986.36, inside Drill Collar of 22807.21, and in the annular between the Casing and the Drill pipe is 2847.435, between Open Hole and Drill pipe 3037.264, and 2679.938 between Open Hole and Drill Collar, and the velocity at which the drill cutting drops when in the annulus in all three zones is 0.14914 fps.

The results of the analysis of fluid flow that occurs are found that in the pipe there is a turbulent flow and in the annulus, a laminar flow occurs. In addition, the results of the analysis of the comparison between the velocity of the drilling fluid in the annulus and greater than the velocity of descent of the cuttings show that the cuttings can be lifted by the drilling fluid successfully. This indicates that the fluid lifting process is successful.

6. Acknowledgements

The Authors are giving credit or appreciation to the Institute Technology Petroleum Balongan that already support this research and publication.

References

[1] F. R. Romdon, "Perencanaan Hidrolika Pemboran," Swara Patra, 9, 2, 43–52, (2019).

[2] F. M. Zakhrifady, "Hidrolika Pemboran Dan Pengangkatan Cutting," Journal of Petroleoum, 7, 1, 5–14, (2018).

[3] A. R. R. Wastu, A. Hamid, And S. Samsol, "The Effect Of Drilling Mud On Hole Cleaning In Oil And Gas Industry," Journal of Physics Conference Series, 1402, 2, 1–6, (2019).

[4] I. Agriandita, "Analisa Pengangkatan Cutting Pemboran Dengan Perhitungan Lifting Capacity," Jurnal Migasian, 5, 1, 60–63, (2021).

[5] A. Rizkina, R. Wastu, O. Ridaliani, And R. Avianti, "Optimasi Hidrolika Dengan Metode

Bhhp Pada Trayek 8 ½ Inch Sumur X Lapangan Y," Petro, 9, 3, 118-124, (2020).
[6] S. Haryono, M. S. Cahyono, And W. W. Mandala, "Analisa V Slip Pada Sumur Bunyu Bsb Dengan Metode Moore V Slip Analysis In Bsb Bunyu Well Using The," Kurvatek, 7, 2, 1–10, (2022).
[7] A. A. Khalil And M. S. Adnan, "Effect Of Mud Rheology On Cuttings' Transport In Drilling Operations," In Iop Conference Series: Materials Science And Engineering, 671, 1, 1–15, (2020).
[8] M. Putra, O. Ridaliani, And A. Wastu, "Evaluasi Pengangkatan Cutting Dengan Menggunakan Metode Cci Dan Pbi Pada Sumur X Trayek 26" Dan 17-1/2"," 495–501, (2018).
[9] F. Ponggohong, M. Ginting, And R. Akbar, "Evaluasi Hidrolika Lumpur Pemboran Pada Pengangkatan Cutting Dalam Trayek 16 Inch Sumur 'F-03' Lapangan 'X,'" Petro,11, 2, 64–70, (2022).
[10] J. G. Speight, Formulas And Calculations For Drilling Operations, 2nd Ed. *Scrivener Publishing*, (2018).
[11] T. Yan, J. Y. Qu, X. F. Sun, W. Li, Y. Chen, And Q. B. Hu, "A Novel Predictive Model Of Drag Coefficient And Settling Velocity Of Drill Cuttings In Non-Newtonian Drilling Fluids," Petroleum Science, 18, 6, 1729–1738, (2021).
[12] Herianto, "Optimization Rate Of Penetration In Directional Drilling With Adjustable Bit Rotating And Hydraulic Hole Cleaning," European Journal of Applied Science, 9, 5, 411–425, (2021).
[13] A. H. Assi, "Enhancing The Lifting Capacity Of Drilling Fluids In Vertical Oil," Iraqi Journal of Chemistry Petroleum Engginering, 18, 3, 3–29, (2017).
[14] M. Al-Yasiri, A. Al-Gailani, And D. Wen, "Numerical Study Of Cuttings Transport Of Nanoparticle-Based Drilling Fluid," Engineering Reports, 2, 5, 1–14, (2020).
[15] B. Guo And G. Liu, Applied Drilling Circulation Systems Hydraulics, Calculations, And Models, 1st Ed. *Gulf Professional Publishing,* (2011).
[16] J. Skenderija, A. Koulidis, V. Kelessidis, And S. Ahmed, "Application Of A Drilling Simulator For Real-Time Drilling Hydraulics Training And Research," In Spe Middle East Oil & Gas Show And Conference,1–12.(2021).