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Using an experimental drilling simulator to study operational parameters in drilled-cutting transport efficiency

M. Dehvedar[1], P. Moarefvand[2*], A.R. Kiyani[1] and A.R. Mansouri[1]

1. Department of Petroleum Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
2- Department of Mining and Metallurgical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

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Abstract

Inadequate hole cleaning can lead to many problems in horizontal and directional wells. In this work, we tried to investigate the cutting transport phenomenon by an experimental directional drilling simulator, considering the differences between the operational and experimental conditions. The inclination, fluid type (water, foam, viscous, and dense), rotary speed (0 and 110 rpm), nozzle bit size (4, 6, and 8 mm), and stabilizer location (8 and 95 cm from the bit) were included in the tests as the main parameters. It could be concluded that the nozzle size and the stabilizer position influenced the hole cleaning time. In vertical wells, by decreasing the nozzle size from 8 mm to 4 mm, the hole cleaning time was increased. The presence of stabilizer reduced the cleaning time, and optimizing the stabilizer position reduced the probability of cutting bed formation in all inclinations. Finally, a third polynomial equation was fitted between the dimensionless mass and the dimensionless cleaning time.

1. Introduction

Poor hole cleaning and cutting bed formation lead to some problems such as hole pack-off, pipe sticking, increase in torque and drag, increase in ECD, formation break down, lost circulation, and decline in ROP. Preventing the cutting bed formation in the annulus is one of the main reasons for using the stabilizers in BHA [1-3]. Doing any research work in field operation has many restrictions such as the financial costs and the operational risks [4-6]. In the present work, some parameters such as pressure, temperature, and stresse did not meet the real situation but the others such as string rotation, drilling fluid, inclination, nozzle size, and annulus matched the operational requirements [7]. The wall type in the drilling operations can be formation rock or stainless steel, while in the simulator, the wall type is plexy glass. There are some limitations in the inclination and their length rather than the actual wells [8]. Usually, the cutting concentration, mean bed height, and length of the bed are the main variables that are traced for hole cleaning efficiency across the annulus [6, 9]. Parameter measurement has been done by the PIV techniques [10, 11] or tomography [12].

The hole cleaning index can be improved by optimizing the operational parameters. The rotation of the drill pipe has a positive effect on this process, especially at low flow rates; the pipe rotation can duplicate the hole cleaning efficiency for low-size cuttings [13, 14]. Also increasing the flow rate improves the process [7]. Usually the required flow rate for re-suspension of cutting in the bed into the fluid is two to three times the required flow rate for settling its prevention [15]. For this reason, an attempt must be made to prevent the cutting settling. The other way for a better cleaning is increasing the viscosity of the drilling fluid. The effect of fluid density is less than viscosity [16]. Increasing the yield point to plastic viscosity ratio can help to improve the cutting transport ability [16].

Corresponding author: parvizz@aut.ac.ir (P. Moarefvand).

With an increase in the inclination from 0 to 90 degrees, the cutting concentration increases and after a specific amount, it decreases at a slower rate [17]. Changing the bit type or weight on bit loading can lead to the generation of different cutting sizes and shapes. The cutting shape and size have a unique role in the hole cleaning [18]. The effect of hydrostatic pressure on the hole cleaning is low but the effect of temperature on decreasing the viscosity can be significant [19].

In this work, it was attempted to detect the effects of the hydrodynamic parameters on the cutting transport phenomenon in an experimental simulator. Also the effects of the operational parameters such as inclination (vertical, horizontal, and inclined), drilling fluid (water, dense fluid, viscous-dense fluid, and foam), cutting type (sand, lime, and silica), cutting size (0.55 mm to 1.7 mm and less than 0.5 mm), rotary speed (0 and 110 rpm), nozzle size (4, 6, and 8 mm), and position of the stabilizer on the cutting transport phenomenon were studied. Finally, it was seen that a third polynomial equation could be used for unitizing the cleaning process based on the dimensionless mass across the dimensionless time.

2. Materials and methods

2.1. Experimental flow loop

An experimental drilling simulator was designed and developed by providing a variety of options for controlling the test settings, i.e. properties of the annulus, drilling fluid, cuttings, drill string, temperature, and pressure, as shown in Figure 1a. The annulus is an acrylic tubing with a length and an internal diameter of 220.0 cm and 9.0 cm, respectively. Increasing the length of the flow loop not only increases the mesh number and consequently the simulation time but also causes some limitations in the inclination range. The inner stainless steel pipe has an outside diameter of 4.3 cm and contains four nozzles with an internal diameter of 0.8 cm. The nozzles are attached to the body of the pipe, as shown in Figure 1b. The inner pipe is connected to an AC motor with a shaft and gearbox, and the rotary speed is controlled by an inverter. The cuttings are injected into the annulus with different rates through a designated inlet. The inclination is also adjusted with two arms from a vertical to a horizontal position. A centrifugal pump is utilized to inject the fluid into the string, and the flow rate is controlled using a flowmeter and a by-pass system installed between the pump and the simulator. At the output, a screen is used to collect the cuttings. A mixer is utilized to prepare the drilling fluid, and a Differential Pressure (DP) transducer records the pressure drop in the annulus, as indicated in Figure 1c.

The drilling simulator mechanism is similar to the drilling operation with minor modifications to suite the laboratory conditions. First, the length of the simulator seems small for a horizontal or inclined flow. Secondly, the jet from the four nozzles has a substantial effect on the cutting transport in the present set-up. The jetting nozzles are placed at a 7.5 cm distance from the origin. Thirdly, in the drilling operation, the nozzle size is usually optimized based on maximizing the jet impact force or hydraulic horsepower but the pattern of placement is not seen in this set-up.

2.2. Experimental formulations

After the cutting generation, different forces act on the particles in their transportation to the surface.

The net force for lifting the particle from the bed is [20]:

$$F_{net-lift} = (F_L - F_{cohesive} - W * \sin\alpha) > 0 \quad (1)$$

The net force for rolling the particle toward the outlet is:

$$F_{net-rolling} = F_D * \sin\phi + \left(F_L - F_{cohesive}\right) * \cos\phi + W * \sin\left(-\alpha - \phi\right) > 0 \quad (2)$$

By considering the above equations, the minimum velocity for lifting and rolling are:

For lifting:

$$v_x = \left\{ \frac{4\left[3\tau_y\left(\phi + \left(\frac{\pi}{2} - \phi\right) sin^2\phi - \cos\phi\sin\phi\right)\tan\phi + d_p\left(\rho_p - \rho\right) * \left(\cos\alpha + \sin\alpha\tan\phi\right)\right]}{3\rho\left(C_{Drag} + C_{Lift}\tan\phi\right)} \right\}^{0.5} \quad (3)$$

For rolling:

$$v_x = \left\{ \frac{4\left[3\tau_y\left(\phi + \left(\frac{\pi}{2} - \phi\right) sin^2\phi - \cos\phi\sin\phi\right) + d_p\left(\rho_p - \rho\right)\sin\alpha\right]}{3\rho\left(C_{Drag} - C_{Lift}\tan\phi\right)} \right\}^{0.5} \quad (4)$$

where g is the gravitational constant (m/s^2), d_p is the particle diameter (m), ρ is the density (kg/m^3), W is the weight force (N), v_x (m/s) is the velocity through the flow direction, ϕ is the repose angle, α is the inclination, and τ_y (Pa) is the yield strength of the drilling fluid.

2.3. Methodology

As mentioned in the previous sections, all the tests were done using an experimental simulator. All the tests can be categorized into two main series. In the first one, there are four nozzles that are located in the body of the pipe with a 7.5 cm distance from the bottom of the annulus, and in the second section, a simplified bit is located at the end of the annulus. The second section tests start by replacing the nozzles in the body of the drill pipe with a simplified bit. Three sizes of nozzles (4, 6, and 8 mm) with two amounts of drill pipe rotation speed (0 rpm (while using downhole motor, the drill pipe rotary speed is zero) and 110 rpm) and three values of flow rate (15, 21, and 23 gpm) were considered to evaluate the effect of bit properties on the hole cleaning process (Figure 2).

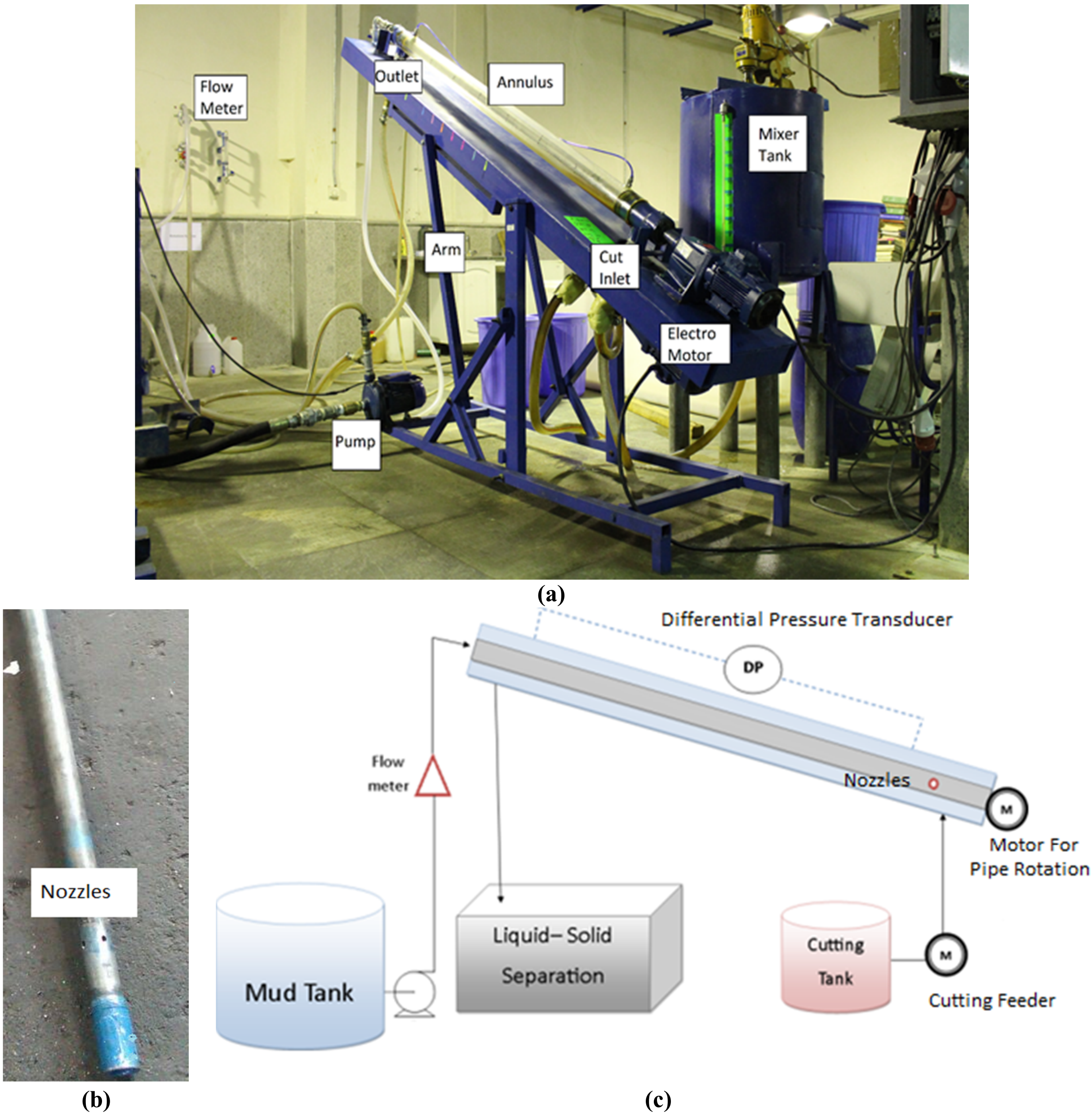


Figure 1. a) Drilling simulator with its diagram. Four nozzles b) and one cutting inlet are located on the right side and one outlet is located on the left side. c)The drilling fluid is pumped through the drill pipe and then comes into the annulus with the nozzles to remove the initial cuttings that are injected through the cutting inlet.

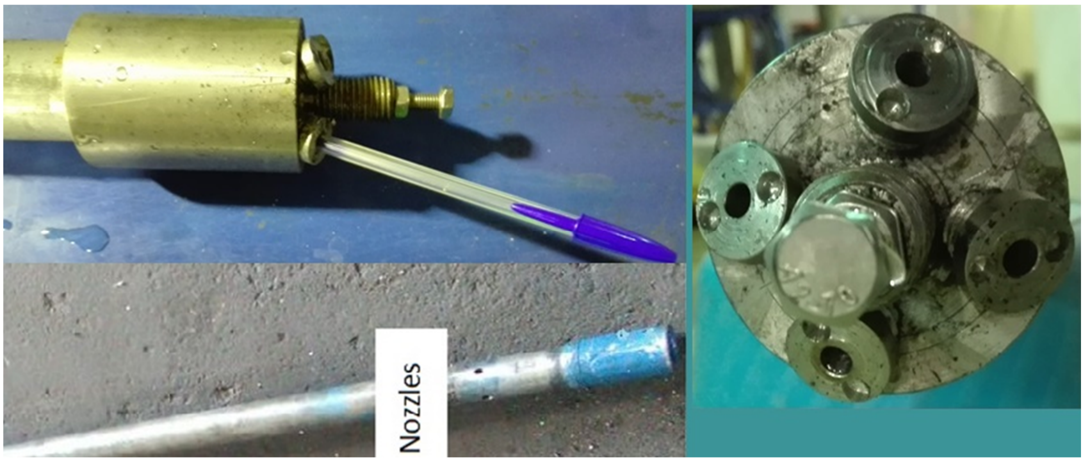


Figure 2. Two types of nozzle arrangements.

The worst inclination for hole cleaning could be detected, as mentioned in the results and discussion section. After identifying it, the effect of rheology on the hole cleaning phenomena was studied using water, water and $CaCl_2$ solution, water and $CaCl_2$ with $PAC\ HV$ as the viscosifier, and finally, with foam. Also the effect of drill pipe rotation on cleaning the fine particles was studied. The effects of particle properties such as the type, size, and shape of the cuttings were the other properties considered. The following figure shows the size distribution and sample particles that were used in different tests. The cutting types and their size distribution are shown in Figure 3. Table 1 shows the experimental tests and the range of the operational parameters.

The differential pressure of the annulus was measured in the tests (in the first category that was related to the positioning the nozzles on the body of the pipe). In the second one, the size of the nozzles could change (4, 6, and 8 mm). The effect of the nozzle size was studied in the vertical section. Finally, the effect of the stabilizer position (8 cm and 95 cm distance from the bit with the nozzle size of 8 mm) on reducing the cutting concentration was considered.

3. Results and discussion

3.1. Critical inclination

The following diagram (Figure 4a) shows that the worst inclination for hole cleaning is related to 55-degree. A similar behavior was seen in the recent studies [5, 21]. By dividing the test time into three groups, they were named as the short duration time, i.e. 6 minutes (HCST), middle duration time, i.e. 12 minutes (HCMT), and long duration time, i.e. 30 minutes (HCLT). As shown, the worst inclination was 55 degrees. The critical inclination is defined where the different diagrams reach each other. By passing the time after the critical inclination, the HCST diagram moves upward until touching the HCLT diagram but before this point, the differences between these diagrams are less. The effect of time after the critical inclination in comparison with the critical inclination period is more evident in the real operation.

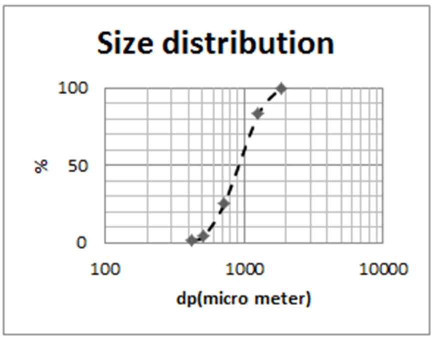


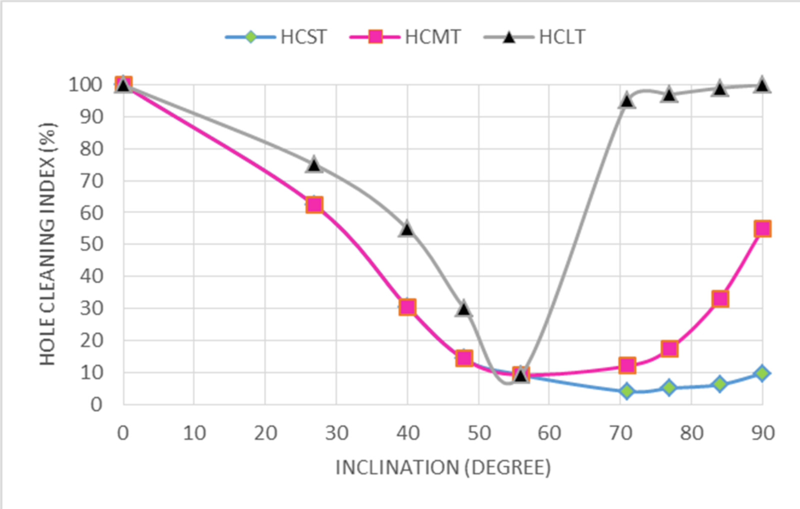
Figure 3. Sand and limestone particles from mesh 10 to mesh 30 and cutting size distribution.

Table 1. The experimental tests on the sand particles and the range of the operational parameters.

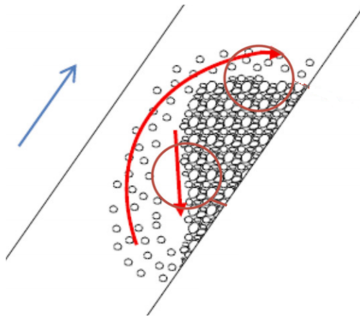
Test No.	Inc. (°)	Flow rate (GPM)	cutting size (mm)	Injected cutting weight (g)	Rotary speed (RPM)	Fluid type	Nozzle type	Nozzle size (mm)	Stabilizer distance (cm)
1	0	31	0.55-1.7	500	110	W^{+}	pipe	8	-
2	25	31	0.55-1.7	500	110	W	Pipe	8	-
3	40	31	0.55-1.7	500	110	W	Pipe	8	-
4	50	31	0.55-1.7	500	110	W	Pipe	8	-
5	55	31	0.55-1.7	500	110	W	Pipe	8	-
6	65	31	0.55-1.7	500	110	W	Pipe	8	-
7	70	31	0.55-1.7	500	110	W	Pipe	8	-
8	75	31	0.55-1.7	500	110	W	Pipe	8	-
9	90	31	0.55-1.7	500	110	W	Pipe	8	-
10	0	17	0.55-1.7	500	110	W	Pipe	8	-
11	0	21	0.55-1.7	500	110	W	Pipe	8	-
12	0	26	0.55-1.7	500	110	W	Pipe	8	-
13	55	31	0.55-1.7	1000	110	W	Pipe	8	-
14	55	31	0.55-1.7	1000	110	W	Pipe	8	-
15	55	31	<0.55	500	110	W	Pipe	8	-
16	55	31	<0.55	500	110	W	pipe	8	-
17	55	31	1.4-1.7	500	110	W	pipe	8	-
18	55	31	0.85-1.4	500	110	W	pipe	8	-
19	55	31	0.55-0.85	500	110	W	pipe	8	-
20	55	31	0.55-1.7	500	110	W-W$^{\alpha}$	Pipe	8	-
21	55	31	0.55-1.7	500	110	V-W$^{\beta}$	Pipe	8	-
22	55	31	<0.55	500	0	W	Pipe	8	-
23	0	17	0.55-1.7	750	110	W	Pipe	8	-
24	90	17	0.55-1.7	750	0	W	Pipe	8	-
25	0	: 3 G: 44	0.55-1.7	1000	110	F$^{\gamma}$	Pipe	8	-
26	55	L: 11 G:88	0.55-1.7	1000	110	F	Pipe	8	-
27	55	L: 3 G: 44	0.55-1.7	1000	110	F	Pipe	8	-
28	90	L: 8 G:44	0.55-1.7	1000	110	F	Pipe	8	-
29	90	L: 8 G: 88	0.55-1.7	1000	110	F	Pipe	8	-
30	0	16	1.4-1.7	500	0	W	Bit	4	-
31	0	21	1.4-1.7	500	110	W	Bit	6	-
32	0	21	1.4-1.7	500	0	W	Bit	6	-
33	0	23	1.4-1.7	500	110	W	Bit	8	-
34	0	23	1.4-1.7	500	0	W	Bit	8	-
35	30	23	1.4-1.7	500	110	W	Bit	8	8
36	30	23	1.4-1.7	500	110	W	Bit	8	95
37	55	23	1.4-1.7	500	110	W	Bit	8	8
38	55	23	1.4-1.7	500	110	W	Bit	8	95
39	90	23	1.4-1.7	500	110	W	Bit	8	8
40	90	23	1.4-1.7	500	110	W	Bit	8	95

The cleaning process time in the vertical section was less than the horizontal and inclined ones. The effect of cutting weight on the settling process was omitted with the upward flow but an adverse impact of the cutting weight was not seen in the horizontal annulus, where the weight force and flow direction were perpendicular to each other. In the inclined period, the weighing force splits into two components, one of them is perpendicular to the low side path line and the other one is on the opposite direction of the flow line. Considering the friction, the cutting bed can move downward and rolling decreases, and as a result, the cleaning time increases (Figure 4b).

The maximum pressure drop is related to zero degrees, and the minimum one is for the horizontal annulus. The following diagram (Figure 5) shows the amount of pressure drop in each inclination. For the inclinations between 30 to 70 degrees, the amounts are very close to each other.

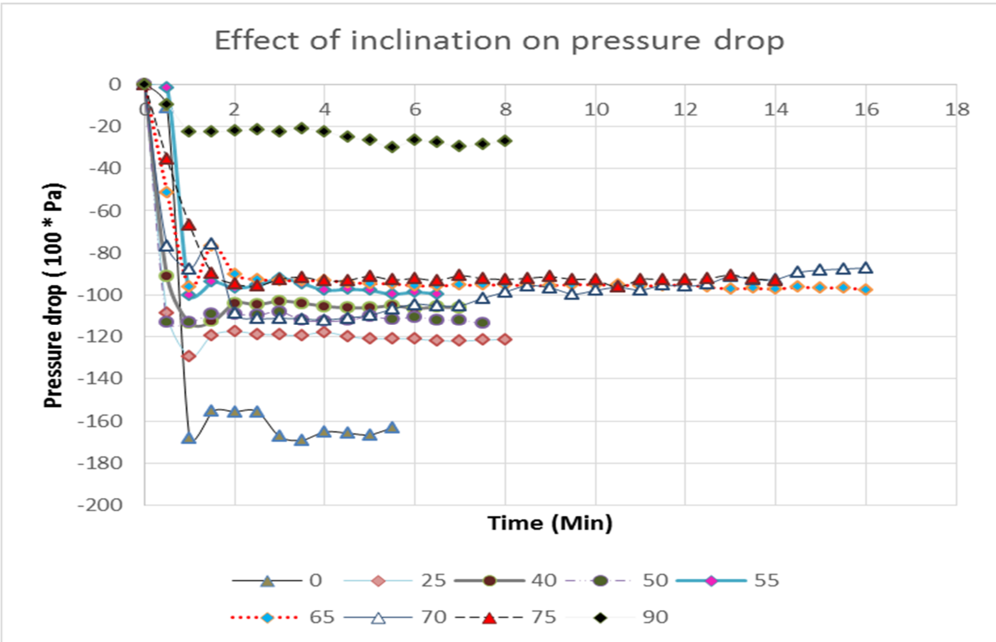


(a)



(b)

Figure 4. a) Hole cleaning index in different inclinations and time periods (After 6 minutes (HCST), 12 minutes (HCMT), and 30 minutes (HCLT)). b) The bed downward movement in the opposite direction of the flow direction in the inclined wells.



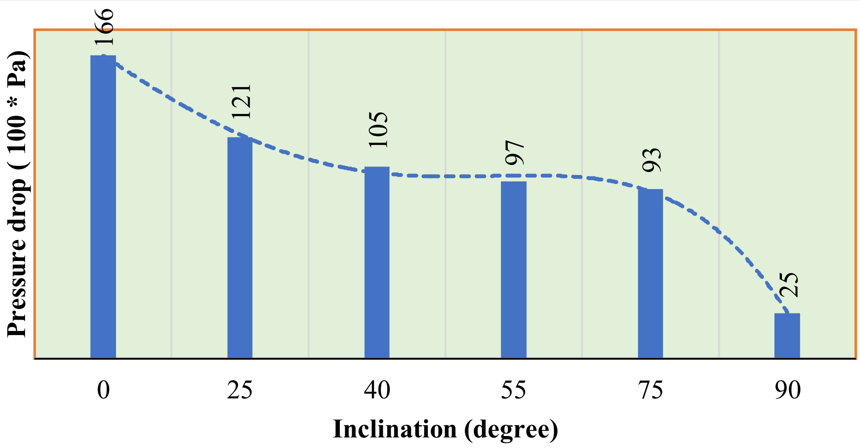


Figure 5. Pressure drop in each inclination.

3.2. Fluid type

In this work, the effects of four fluid types were studied. Table 2 shows the funnel viscosity, density, hole cleaning index, and bed property for the three models. These properties are not easily calculated using foam as a drilling fluid. Figure 6 shows a specific section of the set-up when using these fluids.

By adding $CaCl_2$ to water and mixing it, the density of water increased from 62.4 pcf to 70 pcf, and after testing it by adding viscosifier, the funnel viscosity changed from 32 s to 42 s per quart. This addition does not affect the density of the fluid. The length of the bed increased using the viscosifier. The previous table shows that adding $CaCl_2$ as a weighting agent does not have a significant effect on the hole cleaning process. The bed length only increases by 4 cm, which is negligible when comparing the impact of viscosifiers (51 cm). The following diagram (Figure 7) shows the shear stress and shear rate of the dense viscous fluid at two temperatures (75 F and 187 F).

As it is shown, with an increase in temperature, the ability of fluid in cleaning the annulus is decreased. It must be mentioned that adding viscosifiers caused a decrease in the pressure drop by 10 kpa.

Using foam in the inclined and horizontal sections did not improve the hole cleaning index. The phase separation in foam and density segregation between foam and cuttings did not permit the foam to clean the annulus and cuttings properly. Increasing the amount of gas flow rate and liquid flow rate could reduce phase separation in foam that caused liquid height to decrease on the low side of the well, and as a result, improved the hole cleaning process.

Table 2. Pressure drop in each inclination.

Base fluid + additives	Funnel viscosity (quart/s)	Mud weight (Pcf)	HCI (%)	Bed length (in) (SP-EP)
Water	28	62.4	5.12	15 (10-25)
Water + $CaCl_2$	32	70	6.15	19 (0-19)
Water + $CaCl_2$ + Viscosifier	38	70	10.20	70 (0-70)

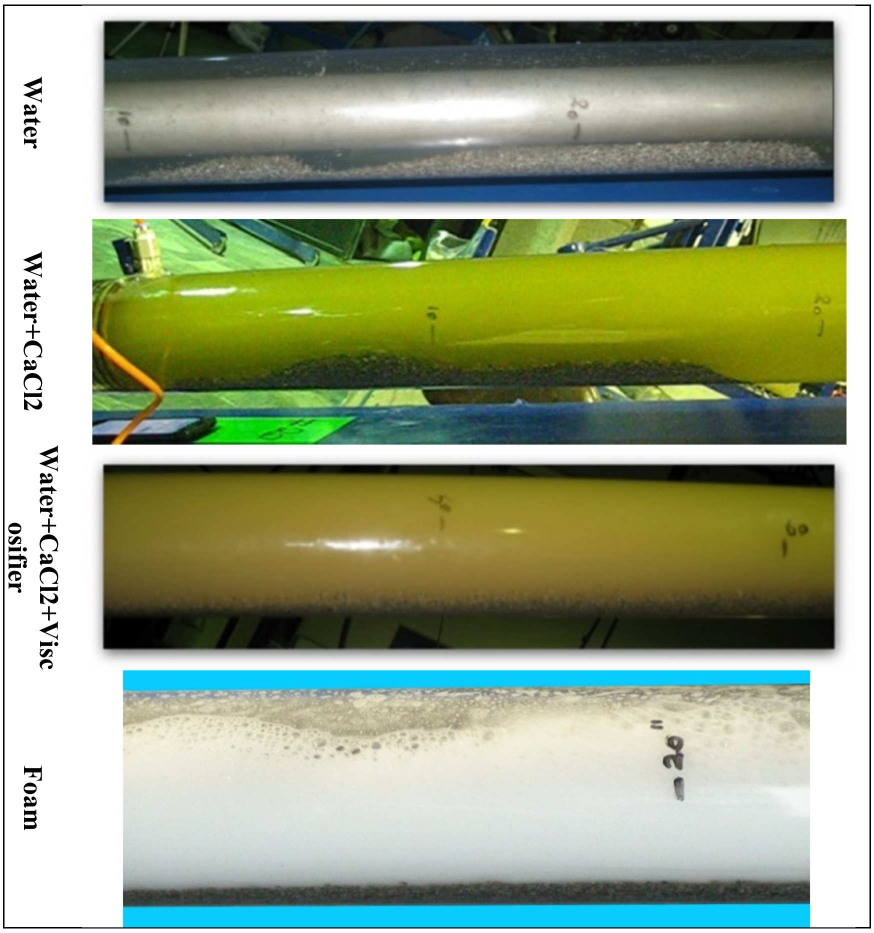


Figure 6. The annulus section with different fluids.

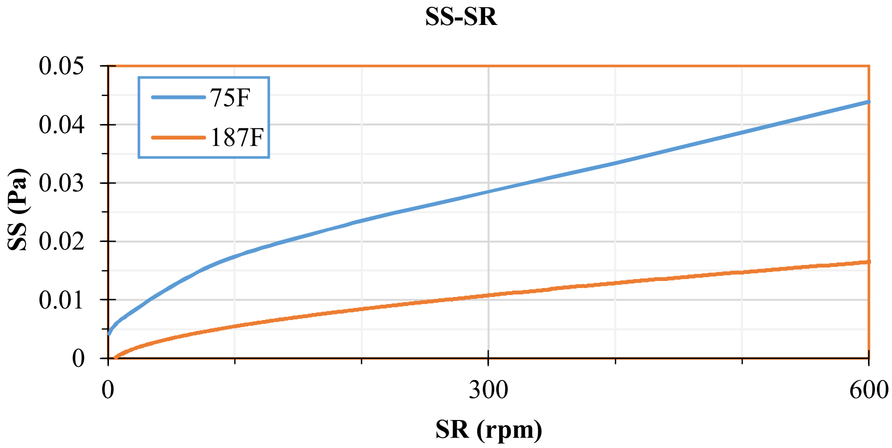


Figure 7. Shear stress and shear rate of the viscous dense fluid at two temperatures (75 F and 187 F).

3.3. Rotary speed

The experimental results illustrate that the rotation of the drill pipe reduces the pressure drop. The effect of rotation on cleaning the fine particles is obvious. Rotation of the pipe shapes small moving hills on the low side of the annulus. Their speed toward the output was constant. By removing the rotation, they joined each other, and a small height moving bed was formed on the low side of the annulus. With this experiment, it could be concluded that the leading cause in creating the hills was the rotation of the drill pipe. Figure 8 shows this difference.

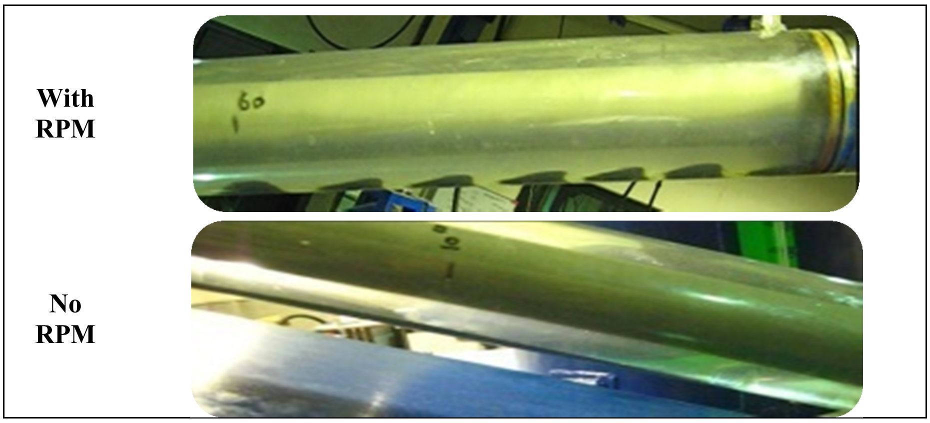


Figure 8. The annulus section with different fluids.

3.4. Effect of cutting type

The effects of three types of cutting (sandstone, lime and silica) on the cleaning process in four sizes (0.55-0.85, 0.85-1.4, 1.4-1.7, and less than 0.55 mm) with two different initial amounts (500 and 1000 g) were studied (Table 3).

By lowering and micronizing the size of the cuttings, the hole cleaning efficiency was sharply increased. In other words, in each condition that results in generating the micronized sands and without any importance in the type of cuttings, the hydrodynamic flow characteristics can improve the cleaning index. With an increase in the penetration rate, the generated cuttings increased, and because of the limitation in the annulus space, a more significant amount could move toward the output. In this condition, the probability of different mechanical pipe sticking increased. The leading solution for similar situations changed the parameters to raise the bed length.

The pressure drop in the combined mesh sizes was more than each one of them separately. For example, the pressure drop for 0.55-1.7 mm was 95 Kpa, and thus for 0.55-0.85, it was 85 Kpa, for 0.85-1.4 mm, it was 70 Kpa, and for 1.4-1.7 mm, it was 85 Kpa. In similar conditions, lowering the size of the cuttings decreased the pressure drop. For example, for cuttings with less than 0.55 mm, the pressure drop was 15 Kpa less than the cuttings with 0.55-1.7 mm.

Table 3. The annulus section with different fluids.

Lithology	SG	Cutting Removal percentage (%)	Description
Sand	2.64	4.11	Sand (0.85-1.4 mm) L ROP (500 g)
		4.41	Sand (1.4-1.7 mm) L ROP (500 g)
		5.12	Sand (0.55-1.7 mm) L ROP (500 g)
		6.58	Sand (0.55-0.85 mm) L ROP (500 g)
		7.55	Sand (0.55-1.7 mm) H ROP (1000 g)
		20.62	Micro Sand (less than 0/55 mm) L ROP (500 g)
Lime	2.54	6.94	Lime (0.55-1.7 mm) L ROP (500 g)
Silica	2.31	22.71	Micro Silica (less than 0.55 mm) L ROP (500 g)

3.5. Nozzle effect

The second section tests were started by replacing the nozzles in the body of the drill pipe with a simplified bit. Three sizes of nozzles (4, 6, and 8 mm) with two amounts of drill pipe rotation speed (0 and 110 rpm) and three values of flow rate (15, 21, and 23 gpm) were considered to evaluate the effect of bit properties on the hole cleaning process. The cutting size range in all second sections was 1.4-1.7 mm. Figure 9 shows the effects of the operational parameters on the cleaning process.

As shown, for a vertical section, with an increase in the flow rate, the hole cleaning process was sharply improved, and with an increase in the size of the nozzles, the ability of the cutting transport was increased. In other words, a decrease in the nozzle size results in more time for removing the cuttings from the annulus. The rotation of the drill pipe cannot be efficient in all conditions. This diagram shows that omitting the drill pipe rotation at 21 GPM causes a faster cleaning rather than rotation.

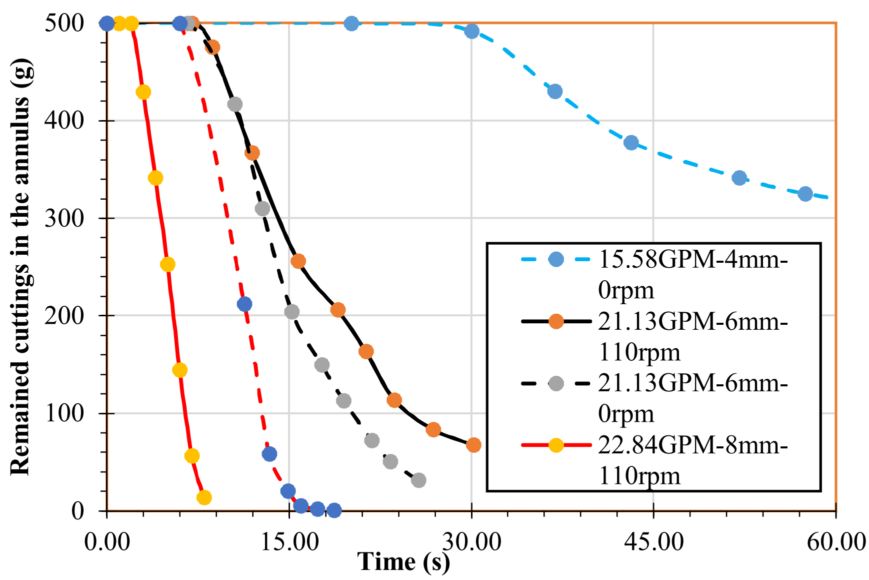


Figure 9. Effects of operational parameters on the cleaning process.

3.6. Stabilizer position

In this work, for detecting the effect of the stabilizer, a simplified stabilizer was located at the two specific distances of 8 and 95 cm of the drill bit. 95 cm was the position in which the cutting bed settling occurred when using the stabilizer in the adjacent bit position (8 cm). Three specific inclinations were selected to be the inclination sample for three periods (30, 55, and 90degrees).

In Figure 10, the stabilizer is located at a distance of 8 cm from the bit.

Figure 11 shows that lowering the distance between the stabilizer and bit has an adverse effect on the cleaning process.

Figure 10. A simplified stabilizer is located at two specific distances of 8 cm of the drill bit.

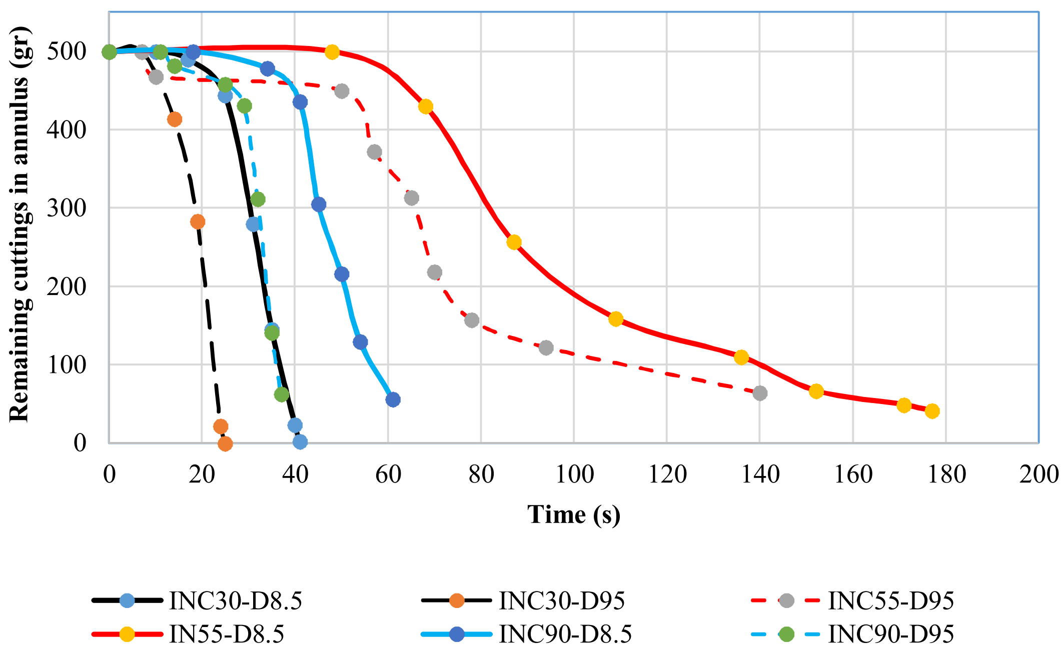


Figure 11. The combination effect of stabilizer and drill bit on the cleaning process time.

The hydraulic horsepower of the drilling fluid was decreased after touching the stabilizer and the initial cutting load. For this reason, the cutting bed formed in the middle of the low side of the annulus and then slowly moved toward the outlet. To solve this problem, the stabilizer was placed in the point where the cutting bed was formed, so rotation of the stabilizer blades helped to disperse the cuttings and pushed them into the outlet. As shown above, the worst results were obtained, respectively, in the 55-degree and 90-degree, and the best result was obtained in zero degrees. In the same way, the 95 cm distance from the bit had better results rather than 8 cm in each section.

Because of the length limitation, more tests must be done to optimize the stabilizer position in the annulus. In this set-up, only one stabilizer was used. Therefore, lowering the distance between the optimized stabilizer position and bit increases the required cleaning time. It must be mentioned that using a packed hole assembly (with more than two stabilizers) enhances the cleaning process in comparison with a single stabilizer style.

Figure 12 shows the remained cuttings in the annulus versus time in the three experimental tests in a vertical annulus with different nozzle sizes.

Figure 13 was plotted for dimensionless mass $ln\left(\frac{M_0 - M_t}{M_t}\right)$ versus dimensionless $\left(\left(\frac{Int}{Int_{1/2}} - 1\right)\right)$. As shown, the relationship between them obeys a third polynomial equation, where Mout is the mass of exited cuttings and Min is the remained mass. $T_{1/2}$ is the necessary time for exiting half of the initial cutting mass and *t* is the elapsed time.

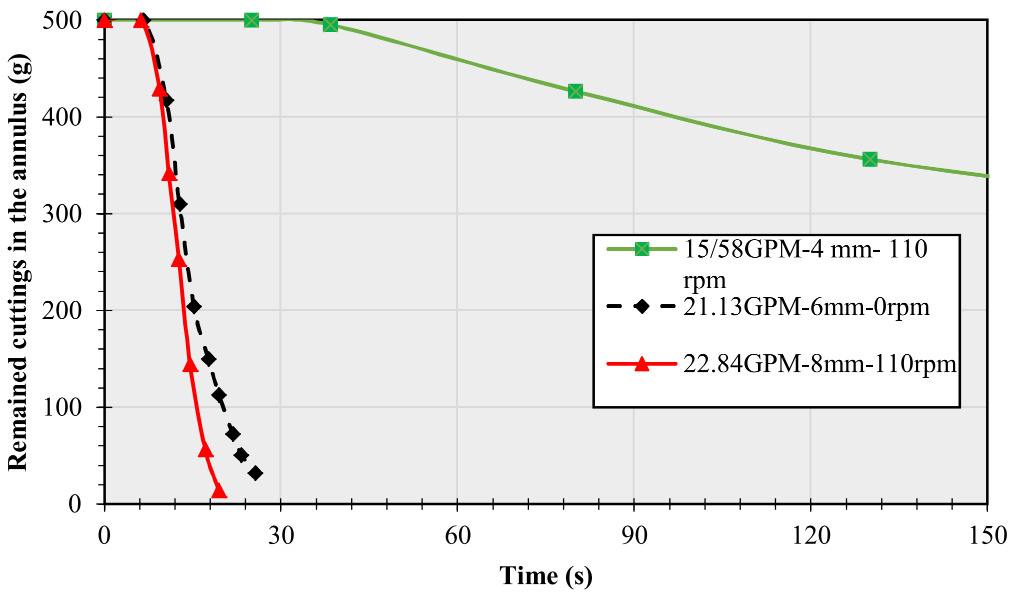


Figure 12. The remained cutting mass in the annulus versus time in three experimental tests in a vertical annulus with different nozzle sizes.

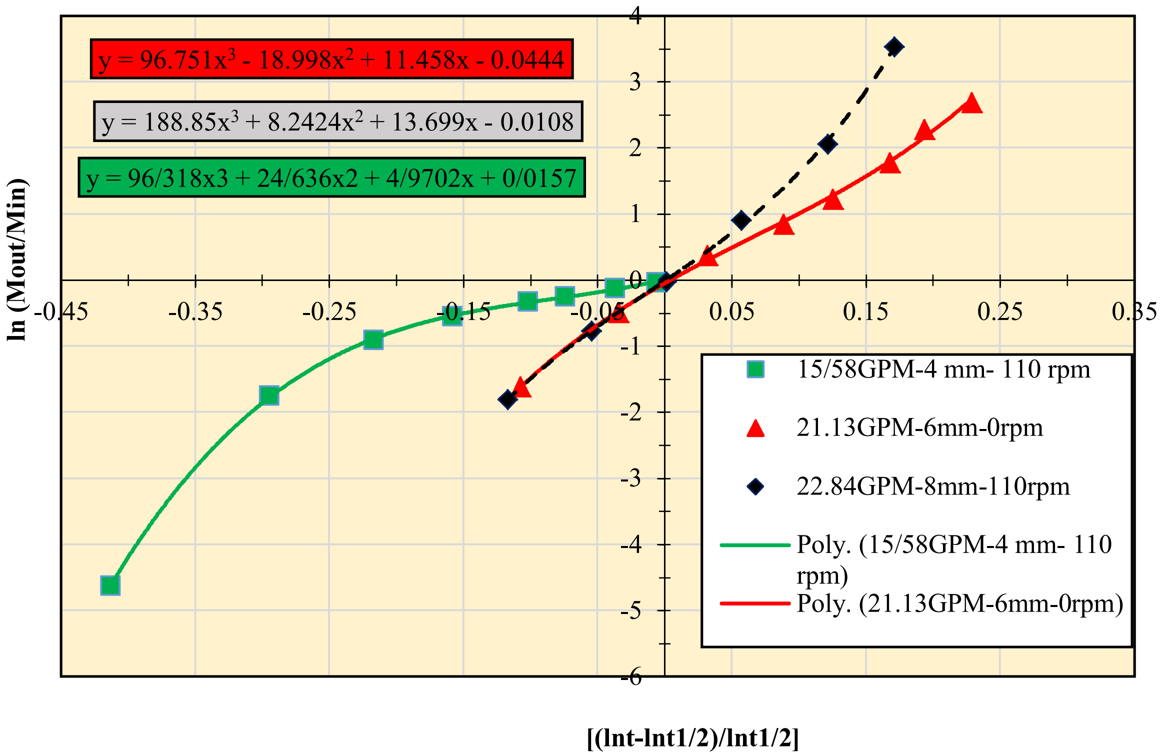


Figure 13. The fitted third polynomial equations with the real data in the experiment for the vertical annulus.

4. Conclusions

In this work, efforts were made to detect the effects of some operational parameters on the hole cleaning time by an experimental circulating flow loop as a directional drilling simulator. In the tests, an attempt was made to remove the initial patched sand using the drilling fluid jetting. In this set-up, the critical inclination for mechanical sticking was 55-degree. The size, shape, and type of the cuttings are essential and have complicated effects on the cutting transport. The drill pipe rotation speed may lead to the generation of moving hills in the low side of the annulus when using the micronized sand. Adding viscosifiers to the low viscous, dense fluids could lead to an increase in the bed length. Due to phase segregation, using foam as the cleaning fluid was not applicable in the horizontal sections. Increasing the nozzle size and flow rate improved the hole cleaning time. With an increase in the nozzle size from 4 mm to 8 mm, the required time for the hole cleaning decreased. Decreasing the distance between the bit and the optimized stabilizer position in the drilling simulator increased the time for the cleaning process in all inclinations. There are a third polynomial correlation and diagram for characterizing the cutting transport in this type of directional simulators.

References

[1]. Uddin, H., Choudhury, N.R. and Ansari, U. (2016). A computational study of pack off using a combined drill bit stabilizer particle tracking simulation. Society of Petroleum Engineers.

[2]. Ayeni, O.O., Wu, C.L., Nandakumar, K. and Joshi, J.B. (2016). Development and validation of a new drag law using mechanical energy balance approach for DEM–CFD simulation of gas-solid fluidized bed. Chemical Engineering. 302: 395-405.

[3]. Amanna, B. and 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.

[4]. Kamyab, M. and Rasouli, V. (2016). Experimental and numerical simulation of cuttings transportation in coiled tubing drilling. Journal of Natural Gas Science and Engineering. 29: 284-302.

[5]. Allahvirdizadeh, P., Kuru, E. and Parlaktuna, M. (2016). Experimental investigation of solids transport in horizontal concentric annuli using water and drag reducing polymer-based fluids. Journal of Natural Gas Science and Engineering. 35: 1070-1078.

[6]. Egenti, N.B. (2014). Understanding drill-cuttings transportation in deviated and horizontal wells. Society of Petroleum Engineers.

[7]. Falcone, G. (2009). Flow loops for validating and testing multiphase flow meters. Developments in Petroleum Science. 54: 295-302.

[8]. Tripathy, A., Bagchi, S., Biswal, S.K. and Meikap, B.C. (2017). Study of particle hydrodynamics and misplacement in liquid-solid fluidized bed separator. Chemical Engineering Research and Design. 117: 520-532.

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

[10]. Sutkar, V.S., Deen, N.G. and Kuipers, J.A.M. (2013). Spout fluidized beds: Recent advances in experimental and numerical studies. Chemical engineering science. 86: 124-136.

[11]. Limtrakul, S., Chen, J., Ramachandran, P.A. and Duduković, M.P. (2005). Solids motion and holdup profiles in liquid fluidized beds. Chemical Engineering Science. 60 (7): 1889-1900.

[12]. Wang, Z.M., Guo, X.L., Ming, L.I. and Hong, Y.K. (2009). Effect of drill pipe rotation on borehole cleaning for extended reach well. Journal of Hydrodynamics. 21 (3): 366-372.

[13]. Duan, M., Miska, S.Z., Yu, M., Takach, N.E., Ahmed, R.M. and Zettner, C.M. (2008). Transport of small cuttings in extended-reach drilling. Society of Petroleum Engineers. 23 (03): 258-265.

[14]. Duan, M., Miska, S.Z., Yu, M., Takach, N.E., Ahmed, R.M. and Zettner, C.M. (2009). Critical conditions for effective sand-sized solids transport in horizontal and high-angle wells. Society of Petroleum Engineers. 24 (02): 229-238.

[15]. Nazari, T., Hareland, G. and Azar, J.J. (2010). Review of cuttings transport in directional well drilling: systematic approach. Society of Petroleum Engineers.

[16]. Mme, U. and Skalle, P. (2012). CFD calculations of cuttings transport through drilling annuli at various angles. International Journal of Petroleum Science and Technology. 6 (2): 129-141.

[17]. Baldino, S., Osgouei, R.E., Ozbayoglu, E., Miska, S., Takach, N., May, R. and Clapper, D. (2015). Cuttings settling and slip velocity evaluation in synthetic drilling fluids. Offshore Mediterranean Conference and Exhibition.

[18]. Peker, S.M. and Helvaci, S.S. (2011). Solid-liquid two-phase flow, Elsevier. 349 P.

[19]. Skalle, P. (2015). Drilling fluid engineering, Bookboon. 85 P.

[20]. Pang, B., Wang, S., Wang, Q., Yang, K., Lu, H., Hassan, M. and Jiang, X. (2018). Numerical prediction of cuttings transport behavior in well drilling using kinetic theory of granular flow. Journal of Petroleum Science and Engineering. 161: 190-203.

[21]. Epelle, E.I. and Gerogiorgis, D.I. (2017). A multi-parametric CFD analysis of multiphase annular flows for oil and gas drilling applications. Computers & Chemical Engineering. 106: 645-661.

استفاده از شبیه‌ساز آزمایشگاهی حفاری برای مطالعه پارامترهای عملیاتی بر بازدهی حمل‌کننده‌های حفاری

محسن ده ودار[۱]، پرویز معارفوند[۲*]، علیرضا کیانی[۱] و علیرضا منصوری[۱]

۱- دانشکده مهندسی نفت، دانشگاه صنعتی امیرکبیر، ایران

۲- دانشکده مهندسی معدن و متالورژی، دانشگاه صنعتی امیرکبیر، ایران

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* نویسنده مسئول مکاتبات: parvizz@aut.ac.ir

چکیده:

تمیز سازی ناکافی چاه می‌تواند موجب ایجاد مشکلات زیادی در چاه‌های افقی و جهت‌دار شود. در این پژوهش سعی در بررسی پدیده حمل کننده با در نظر گرفتن تفاوت‌های موجود بین شرایط عملیاتی و آزمایشگاهی، با استفاده از یک شبیه‌ساز جهت‌دار آزمایشگاهی شده است. زاویه انحراف چاه، نوع سیال حفاری (آب، کف، سیال با گرانروی بالا و سیال با وزن بالا)، سرعت چرخش رشته حفاری (صفر و ۱۱۰ دور بر دقیقه)، اندازه نازل‌های مته حفاری (۴، ۶ و ۸ میلی‌متر) و مکان پایدارکننده (۸ و ۹۵ سانتی‌متری از مته حفاری) به عنوان پارامترهای اصلی در آزمایش‌ها در نظر گرفته شده‌اند. اندازه نازل‌های مته حفاری و مکان پایدارکننده بر زمان تمیز سازی اثر گذاشت. در چاه عمودی، با کاهش اندازه نازل از ۸ به ۴ میلی‌متر، زمان تمیز سازی چاه افزایش یافت. حضور پایدارکننده زمان تمیز سازی را کاهش داد و با بهینه‌سازی مکان پایدارکننده، احتمال تشکیل بستر کننده در همه زاویه‌های انحراف کاهش یافت. در نهایت همبستگی اعداد بدون بعد جرم کننده و زمان تمیز سازی بدون بعد با استفاده از یک معادله چندجمله‌ای درجه سوم صورت پذیرفت.

کلمات کلیدی: شبیه‌ساز حفاری، پایدارکننده، نازل مته، پارامترهای عملیاتی، همبستگی.