Study of Cleaning the Horizontal Drains during the Under Balanced Drilling Well in the South Algeria Fields

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Abstract. Many difficulties can occur during the well is being drilled directionally, as cuttings may accumulate either in a bed at hole high angles. It is to highlight that the speed of the cuttings depends on the geometry of the drilling and the amplitude of the ROP. Hole cleaning is still among the most important problems to solve during the drilling operations. The difficulty in removing cuttings bed during drilling appears due to the interaction between drilling mud and the cuttings in cuttings bed leading to the formation of a cuttings bed gel. Inefficient cleaning of the wellbore can cause decrement in the stuck pipe, lost circulation, wellbore instability, high torque and drag, loose control on density, bad quality cement jobs, etc. These problems have a major impact on the economics of the drilling process. Optimization of the hole cleaning during the drilling operations is very important to enhance the drilling rate. In this study, the Rubiandini and Zhou models have been applied to the well for the prediction of the flow rate required to the ascent of cuttings to the day and to prevent the formation of the beds. The results show the critical flow rate value calculated by the Zhou model (544 l/min) to be lower than the in-situ applied flow rate (720 l/min), while for the Rubiandini model, the critical flow is higher (843.16 l/min for the rotary and 783.01 l/min for the sliding). The model of Rubiandini was chosen to make the sensitivity study because the flow rate calculated by this model is close to reality. We highlighted the effect of major drilling parameters, such as ROP, mud rheology, specific gravity of fluid, density of cuttings, dimension of cuttings, flow rate, flow regime, and rotating speed of the drill string on cuttings transport efficiency are analysed.

1. Introduction

Under balanced drilling (UBD) is a technique used to drill hydrocarbons wells where the pressure of the drilling fluid in the well is kept below the reservoir pressure during the drilling of the formation. It is often used to preclude formation damage, avert lost circulation, and increase rate of penetration [1]. Among important functions of a drilling fluid is to transpose the cuttings to the surface across the annulus. Parameters affecting the ability of drilling fluids to move cuttings are (i) rheological properties and flow rate, (ii) particle settling velocities, (iii) particle size, (iv) ROP of drill bits, (v) rotary speed of drillstring, (vi) fluid specific gravity (vii) annulus inclination [2]. According to Hussaini et al. [2] the fluid annular velocity has a major effect on the carrying capacity of the drilling muds, and the Increasing of the ratio of yield point to plastic viscosity raises the carrying capacity of mud. For many years, the problems of stuck pipe are still posed during the drilling operation because of the inefficient removal of drilled cuttings from the borehole annulus [3]. Whereas these problems can
exist in drilling vertical wells, but they are most frequent in drilling deviated wells [4]. The numbers of highly deviated and horizontal wells have increased significantly because of technological progress in the drilling domain. During the drilling operation, cuttings bed is deposited in horizontal or inclined sections when the flow rate of drilling fluid at the level of annular is low [5]. In literature, there are many studies on hole cleaning has been conducted by different authors [6-11]. Larsen [12] carried out an experimental study on the cuttings deposition with a view to determine the critical flow velocity for cuttings transport in an inclined wellbore with a drilling mud for single phase. He took into account several drilling parameters which can influence the cuttings transport as, well inclination, drilling fluid rheology, annular velocity, cuttings size, mud specific gravity, pipe eccentricity and drill string rotation [6]. He found that low viscosity has a better cutting transport capacity in comparison to high viscosity mud.

2. Simulation and evaluation of the state of well cleaning

The presence of the bed of cuttings in the "Build Up" part of the horizontal wells is the first consequence of insufficient transport of the cuttings produced as the drilling tool progresses, it is for this because it is considered to be a criterion for assessing the condition of hole cleaning. Cuttings bed thickness simulation is performed by the WELLPLAN software. The parameters mentioned in table 1 are the actual parameters of the drilling which was sliding up to 3554 m and the rest was in rotary, up to 3720 m.

| Table 1. Data of drilling parameters |
|--------------------------------------|
| Drilling parameters          | rotary mode | Sliding mode |
|--------------------------------|-------------|--------------|
| ROP(ft/h)             | 26.5        | 19.69        |
| Speed rotary(rpm)      | 40          | 0            |
| Mud density(ppg)        | 6.84        | 0.109        |
| Plastic viscosity(cP)   | 2.0         | 2.0          |
| Yield value(lb/100 ft²) | 0.0         | 0.0          |
| Drill pipe diameter(in) | 3.5         | 3.5          |
| Cuttings density(ppg)   | 22.6        | 22.6         |
| Cuttings Size (in)      | 0.05        | 0.05         |
| Flow rate of drilling pump(gal/min) | 190.20     | 190.20       |

Figure 1. Thickness of bed of cuttings as a function of depth
From figure.1, we note that there is a deposit of cuttings in the form of a bed with a length of 300 m (from 3390 m up to 3710 m) for the rotary and 210 m (from 3330 m up to 3540 m) for sliding and an average thickness of 11.62 mm. The greatest thickness is in front of the depth 3510 m which corresponds to an inclination of 65.2 °.

3. Flow rate for hole cleaning
In this step, the Rubiandini and Zhou models will be applied to the well for the prediction of the flow required for the rise of cuttings and the prevention of bed formation. As in the case of the previous simulation, we apply the same real parameters for both models.

3.1. Rubiandini model
Based on formulas and correlations of this model, we have programmed a calculation code in the MATLAB language which allows us to calculate the flow rate recommended by Rubiandini and to present the critical flow curves as a function of well inclination and depth (figure 2-3).

3.2. Zhou model
The critical flow is calculated, the variation of the critical flow as a function of the depth is presented in figure 4.
We note that the value of the critical flow calculated by the Zhou model (544 l / min) is lower compared to the actual flow rate (in-situ) (720 l / min), so if we drill with this flow we will complicate more the things, because this model is a mechanistic model based on the analysis of forces and moments acting on the solid particle. To formulate the velocity of the fluid necessary for the destabilization of the bed and to put the cuttings in movement and afterwards their transport until the exit of the well, it is necessary to take into consideration several parameters which have a great impact on the cleaning such as the rotational speed (RPM) and the rate of penetration (ROP) [13]. While the Rubiandini model is based on experimental studies with the aim of establishing empirical relations of the critical velocity, in addition, it takes into account in its model parameters that have been neglected in the Zhou model, it is for this reason, the critical flow rate, in this case, is higher (843.16 l / min for rotary and 783.01 l / min for sliding).

4. Effects of drilling parameters on cuttings transport

We will approach the influence of drilling parameters (mechanical and hydraulic) on the critical transport speed of cuttings according to the Rubiandini model. In the following, we will each time vary a single parameter by fixing the others. Also, we will see the direct influence of some parameters on the cleaning index.

4.1. Effect of rate of penetration

The variation of the required minimum velocity as a function of the inclination for different values of ROP is shown in figure 5.

For the lowest value of ROP (ROP = 6 m / h) we can draw the following observations:

- for the inclination angle 0°, the critical flow velocity corresponds to a value of the order of 2.64 ft / s
- from the angle of inclination 45° up to 90°, the critical flow velocity remains constant and corresponds to a value of 3.5 ft / s.

For the other values of ROP (ROP = 12 m / h and ROP = 16 m / h), the values of the critical speeds for the vertical and horizontal sections are mentioned in table 2.
Table 2. Flow velocity at different values of ROP

| Well section | Flow velocity (ft/s) |
|--------------|----------------------|
| ROP = 6 m/h  |                       |
| Vertical: 0° | 2.64                 |
| Horizontal: 45° à 90° | 3.5         |
| ROP = 12 m/h |                       |
| Vertical: 0° | 3.45                 |
| Horizontal: 45° à 90° | 4.32         |
| ROP = 16 m/h |                       |
| Vertical: 0° | 3.77                 |
| Horizontal: 45° à 90° | 4.64         |

It can be seen that the increase in ROP causes the increase in the critical flow velocity and subsequently the increase in the critical flow rate of cuttings transport. This is due on the one hand to the increase of the volume of the cuttings compared to that produced in case of a lower ROP, and on the other hand to the increase of the velocity of the cuttings (Vcut) according to the correlation established by Moore. It can be seen that the index of cleaning decreases as a function of the increasing of ROP (figure 6).

4.2. Effect of mud rheology on cuttings transport

Figure 7 presents the variation of the required minimum velocity as a function of the inclination of the hole for different values of plastic viscosity and yield point. Three types of drilling fluid were chosen: crude oil, low vis mud and high vis mud.

![Figure 7. Flow velocity versus hole inclination with three types of mud](image)

For crude (PV = 2 cp and YP = 0 lb / 100ft²) the following observations can be made:
- For the 0° inclination angle, the critical flow velocity is 2.97 ft/s.
- For the 45° inclination angle up to 90°, the critical flow velocity remains constant and corresponds to a value of 3.84 ft/s.

For other types of mud (low vis and high vis), the values of the critical velocity for the vertical and horizontal sections are given in table 3.

Table 3. Values of flow velocity with three types of mud

| Hole section                  | Vertical: 0° | Horizontal: 45° à 90° |
|------------------------------|--------------|-----------------------|
| Crude oil (PV= 2 cp YP= 0 lb/100ft²) | 2.64         | 3.5                   |
| Low vis mud (PV= 4 cp YP= 6 lb/100ft²) | 3.45         | 4.32                  |
| High vis mud (PV= 10 cp YP= 19 lb/100ft²) | 3.77         | 4.64                  |
From the results mentioned in table 3, it is noted that the increase of the plastic viscosity and the yield point causes the increase of the critical velocity of flow and subsequently the increase of the critical flow of the transport of cuttings.

4.3. Effect of specific gravity on cuttings transport

Figure 8 illustrates the variation of the required minimum velocity versus inclination for different values of drilling fluid density.

For the lowest density value ($df = 5.007$ ppg) the following observations can be made:
- for the inclination angle $0^\circ$, the critical flow velocity corresponds to a value of the order of 3.17 ft/s
- from the angle of inclination $45^\circ$ up to $90^\circ$, the critical flow velocity remains constant and corresponds to a value of 4.07 ft/s.

For the other density values ($df = 6.843$ ppg and $df = 7.928$ ppg), the critical velocity values for the vertical and horizontal sections are given in table 4.

| Table 4. Values of flow velocity at different values of density |
|---------------------------------------------------------------|
| Well section | Vertical: $0^\circ$ | Horizontal: $45^\circ$ to $90^\circ$ |
|------|------------------|------------------|
| $df = 5.007$ ppg | 3.17 | 4.07 |
| $df = 6.843$ | 2.97 | 3.84 |
| $df = 7.928$ ppg | 2.89 | 3.74 |

From table 4, it is obvious that the increase in the density of the drilling fluid causes the decrease in the critical flow velocity and subsequently the decrease in the critical flow rate for the transport of cuttings.

4.4. Effect of density and size cuttings

From Figure 9, it is observed that the critical flow velocity increases with the increase of the cuttings density. The denser a particle is, the more it tends to settle on the lower wall of the well (the horizontal part), this is due to the gravitational forces acting on the particle, which requires a flow velocity sufficient to overcome these forces.
From Figure 10, we observe the variation of the minimum velocity required according to the inclination angle for different values of cuttings diameter.

![Figure 9](image1.png)  
**Figure 9.** Flow velocity versus hole inclination with various density of cuttings

![Figure 10](image2.png)  
**Figure 10.** Flow velocity versus hole inclination with various size of cuttings

With regard to the smallest diameter value (Dcut = 0.05 in), we note that:

- For an inclination angle of 0 °, the critical flow velocity corresponds to a value of 2.98 ft / s
- With an inclination angle that oscillates between 45 ° up to 90 °, the critical flow velocity remains constant and corresponds to a value of 3.84 ft / s.

### 4.5 Effect of rotary speed of drill pipe

We see that the rotation of drill pipe string participates in the cleaning of the horizontal drain (figure 11). The higher the rotation, the cleaning index is improved. By the rotating effect of the drill pipe, the solid particles are put in motion which improves their transport.

![Figure 11](image3.png)

**Figure 11.** cleaning index as a function of rotary speed
5. Conclusions

The use of a simulator is a very useful way to control well cleaning because it allows us to get an idea of what is going on at the bottom of the well. The simulation result shows that controllable parameters, drilling fluid and cutting parameters have an effect on cutting hole cleaning. However, sufficient flow rate can improve hole-cleaning provided that this flow rate does not induce fracturing in the formation. Therefore, during the design phase, hole-cleaning optimization study is very important. From our study, it can be concluded that the mathematical models remain a means of approach and do not accurately reflect the reality of the well drilled. The experimental method remains the most reliable way to give the true face of well cleaning. This method allows for a mass balance of solids that have evacuated from the well and those that form a bed in the drain. The drilling fluid plays a very important role since it is the essential mean to deal with this problem. For this reason, all rheological and hydraulic parameters must be well chosen. The fluid annular velocity has a major effect on the carrying capacity of the drilling muds.

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