

Estimation of optimal lifting capacity in annulus

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ABSTRACT

The optimum drilling of oil and gas wells are achieved by reduce costs and time, which will be accomplished with an optimal hydraulic cleaning program. Drilling fluid characteristics, drilling parameters, and well geometrics are regarded as major categories for achieving an optimal hydraulic program based on depth, penetration rate, and flow rate. This study was used a set of equations that related directly and indirectly to estimate the optimal cleaning efficiency in annulus. The procedure is applied here using actual data from an Iraqi oil field to determine the limitation of all parameters that affect the lifting capacity. Cutting transform was regarded as a major element of the well cleaning program as a result of constraints such as avoiding high surge pressure during lifting pipes, high swab pressure when downloading pipes, and fluid loss during rotation. An increase in annular space indicates a decrease in the capacity of drilling fluid to lift cuttings to the surface and an increase in dynamic shear stress. Also, an increase in cutting size, which has a direct relationship with penetration rate that can be effect for cleaning efficacy in annulus.

Keywords: Hydraulic, Cutting, Dynamic shear stress, Annular space, Rheological

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1.Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results. The procedure of selecting appropriate values for indicators of the features of the drilling fluid as well as the flow system during rotation in the well is perhaps the most significant step in planning the technology of cleaning a well from the cuttings. It is vital to identify the objective, identify the consequences, and specify their limitations in order to manage any operation. The majority of study has centered on this area in order to build the well precisely with the least cost and effort. It is widely acknowledged that laying together a well-organized program is important. It is based on a series of interrelated recommendations arising from a thorough examination of the substance of the phenomena that accompany the well cleaning activity [1-3].

Such recommendations, however, are stated in the form of mathematical relations, such as models, which indicate the legality of modifying a coefficient or in connection to influencing elements. Unique pattern should be evaluated and connected. The well clean program's hydraulic plan is frequently based on hydraulic loss estimates, which are dependent on specific pump and drilling fluid parameters. Empirical connections will only represent the statistical average values of the actual well clean efficiency level, regardless of their link to the structural and mechanical features of the drilling fluid. Furthermore, the colloidal stability of drilling fluids was not taken into account in this planning [4-6].

It can identify the parameters of the drilling fluid and hence monitor the well drilling. As a result, researching for effective well cleaning program planning reflects on the success of drilling operations, which implies achieving the end goal of drilling with the least amount of time and effort.

1.1. 1. Drilling well clean program

Drilling fluids are non-Newtonian fluids exhibiting pseudoplastic behavior, meaning their viscosity reductions as the shear rate increases. As a result, this sort of fluid has a large variety of potential rheological interactions. The bulk of non-Newtonian fluids are represented by power-law and Bingham-plastic models, which are chosen and used in this work to accomplish the essential computations [7-9]. The first step in estimating hydrodynamic bottom hole pressure is to choose the optimum model for the real connection between shear rate and shear Stress [10].

1. Includes a well clean program for each stage of drilling selection:
 1. Selecting the appropriate drilling fluid and installing it at each drilling stage.
 2. Selecting drilling fluid qualities (after determining its type and composition).
 3. Selecting the most appropriate indications for the drilling head's work.

In order to ensure the success of any well cleaning program, each feature of the drilling fluid (density, viscosity, gel strength, solid phase concentration, leaching loss, etc.) must be linked to the fluid's ability to perform its basic functions that is the ability to lift and suspend cutting during stopping and the ability to release pumps at returner [10]. Drilling cuttings transport has a significant influence on the drilling process's costs [11]. Ineffective hole cleaning from cuttings can result in a variety of issues, including stuck pipes, reduced bit weight, and reduced rate of penetration (ROP), transient hole blockage, lost circulation conditions, increased pipe wear, increased drilling fluid costs, and wasted time due to wiper tripping.

As a result, a design model for drilling fluid carrying capacity for drilling wells must be developed by combining two studies: non-Newtonian fluid flow through an annulus in both laminar and turbulent flow regimes, as well as cutting transport using non-Newtonian fluids through an annulus.

2. Mathematical model

The parameters of the drilling fluid are chosen by examining the impact of each property on the drilling fluid's functions and attempting to predict this effect using mathematical or experimental correlations.

To ensure that the drilling fluid performs its basic functions (regardless of its type or composition) without regard to the assumed conditions, the ability of the drilling fluid to perform its functions with an efficiency appropriate to the drilling conditions and requirements must be limited when changing the indicators of these characteristics.

The limits on the well cleaning program are summarized in the table below, along with their underlying mathematical formulas.

Table 1. Describe the well-clean program's constraints and the underlying mathematical equations

Basic Mathematical Equations		The constraint
$Vc < w_f - Vs$		Cuttings lift
Pipe lift	$P_{ST} - \Delta P_{UST} \geq P_{fr}$	Pressures
Pipe download	$P_{ST} + \Delta P_{CT} \leq P_{fr}$	
liquid circulation	$P_{ST} + \Delta P_{Cr} \leq P_{fr}$	
On the pumping line	$\sum \Delta P_i \leq [P]$	
Pump back	$P_{\theta} = \frac{4L}{D_b - dp} \times \theta_t \leq P_{fr} - P_{st}$	
Optimum energy	$\Delta P_{OB} = \frac{n}{n+1} \times P_s \cong 0.65P$	

Basic Mathematical Equations		The constraint
$v_{cr} = 25 \cdot \sqrt{\tau_y / \rho_m}$		Flow regime
$Kc = \frac{\tau_y}{\mu - \mu_{min}} \leq 4500 \text{ S}^{-1}$		Sedimentary evidence
For turbine	$Q \geq [Q_T]$	Flow
For jet nozzle	$Q \geq \frac{1}{\Phi_p} \cdot A_{Noz} \cdot [v_j]$	
Bottom cleaning	$Q \geq F_{OB} \cdot [q]$	
$AX\rho XQ^2 + BX\mu_p XQ + CX\tau_y \leq [P]$		Pump capacity
$\rho \geq \rho_{min}$		Well stability
$\theta_1 = 0.5(2 - e^{-110d_0})x d_0 x (\rho_c - \rho_{mc})$		Cutting suspend
$\Phi_m \geq \emptyset$		Filtration fluid

The mathematical concepts formulae in the previous table, for the constraints and situations considered on the characteristics of the drilling mud and its flow indicators, can be adapted in whole or in part, corrected, or developed in response to drilling conditions and the advancement of drilling fluid techniques and pumping methods, and so on.

1.2. Selection of a well clean program

To make the mathematical formulation of the relationships representing constraints on the properties of the drilling fluid, which are summarized in table (1), we simplify the relationship by choosing the most common case of drilling wells (laminar flow in the annulus and turbulent flow pipe), because the relationship can be formulated in the form of first-order linear mathematical equations for each constraint on the properties of the drilling fluid (see Table 2.)

Table 2. Formulation of the linear relationship of constraints depending on the properties of drilling fluids

No	The limitation	Mathematical relationship
1	Cuttings lift	$a_1\mu_p + b_1\tau_y \geq c_1$
2	Avoid high surge pressure	$a_2\rho - b_2\mu_p - c_2\tau \geq P_{fr}$
3	Avoid high swap pressure	$a_3\rho + b_3\mu_p + c_3\tau_y \leq P_{fr}$
4	Avoid fluid loss during rotation	$a_4\rho + b_4\mu_p + c_4\tau_y \leq P_{fr}$
5	Pressure drop by using pump	$a_5Q^2\rho + b_5Q\mu_p + c_5 \leq P$
6	Colloidal stability for drilling mud	$-a_6\tau_y + b_6\mu_p \geq c_6$
8	Jet nozzle for the purpose of cleaning	$Q \geq a_8[Q]$
9	Gel strength to suspending cuttings	$a_9\theta_1 + b_9\rho \geq c_9$
10	Avoid high gel strength to prevent fluid loss	$a_{10}\rho + b_{10}\theta_{10} \leq P_{gr}$
11	filtration quantity	$\Phi_m \geq \emptyset$
12	solid phase concentration	$C_1Q\mu_p + C_2 \rightarrow \min$

The First limitation Constants: Cuttings lift

$$a_1 = 3,33.w_f.[w_f.(D^2 - d^2).0,05.\rho_m - v_m.D_{BIT}^2.(\rho_c - \rho_m)] \quad (1)$$

$$b_1 = 0,535.(D - d).[w_f.(D^2 - d^2).0,05.\rho_m - v_m.D_{BIT}^2.(\rho_c - \rho_m)] \quad (2)$$

$$c_1 = 0,6192.(\rho_c - \rho_m).d^2.w_f.(D^2 - d^2).0,05\rho_m \quad (3)$$

The Second limitation Constants: Avoid high surge pressure

$$a_2 = g.L \quad (4)$$

$$b_2 = \frac{16.v_{ust}l}{(D^2 - d^2)(\ln\frac{D}{d} - 10)} \quad (5)$$

$$c_2 = \frac{4L}{D-d} \quad (6)$$

The Third limitation Constants: Avoid high swap pressure

$$a_3 = gL \quad (7)$$

$$b_3 = \frac{33 V_{CT}}{(D-d)^2} \quad (8)$$

$$c_3 = 0$$

The Fourth limitation Constants: Avoid fluid loss during rotation

$$a_4 = gL \quad (9)$$

$$b_4 = \frac{51LQ}{(D^2 - d^2)(D-d)^2} \quad (10)$$

$$c_4 = \frac{6.66 L}{D.d} \quad (11)$$

The Sixth limitation Constants: Colloidal stability for drilling mud:

$$a_6 = 1$$

$$b_6 = 4500$$

$$c_6 = \mu_{min} \cdot 4500 \quad (12)$$

3. Sample calculations and results

This study was directed towards a set of equations that related directly and indirectly to estimate the optimal cleaning efficiency in annulus. The procedure is applied here using actual data from an Iraqi oil field to determine the limitation of all parameters that affect the lifting capacity design. Calculations for the first section:

- Depth: H=3520ft
- Penetration rate : Vm= 0.18923 ft/min
- Mud density: $\rho_m = 69.94 \text{ lb/ft}^3$
- Flow rate: Q= 13217 bbl/day

Table 3. Linear Equations for Relationship $\tau_y = f(\mu_p)$ at depth 3520 ft

No.	Describe the limitation	Mathematical relationship
1	Cuttings lift	$3.86\mu_p + 0.132\tau_y \geq 0.0398$
2	Avoid high surge pressure	$41.45\mu_p - 0.49\tau_y \geq -0.78$
3	Avoid high swap pressure	$\mu_p \geq 3098$
4	Avoid fluid loss during rotation	$40.7\mu_p + 3.4\tau_y \geq 203.2$
6	Colloidal stability for drilling mud	$4500\mu_p - \tau_y \geq -21.9$
10	Avoid high gel strength to prevent fluid loss	$\theta_T \approx \tau_y \leq 278.71$

Calculations for the second section:

- Depth: H=4300 ft
- Penetration rate: Vm= 0.1493 ft/min
- Mud density: $\rho_m = 76.53 \text{ lb/ft}^3$
- Flow rate: Q= 15173 bbl/day

Table 4. Linear Equations for Relationship $\tau_y = f(\mu_p)$ at depth 4300 ft

No.	Describe the limitation	Mathematical relationship
1	Cuttings lift	$6.53\mu_p + 0.11\tau_y \geq 0.053$
2	Avoid high surge pressure	$46.98\mu_p - 0.63\tau_y \geq -0.34$
3	Avoid high swap pressure	$\mu_p \geq 3379.8$
4	Avoid fluid loss during rotation	$50.9\mu_p + 4.01\tau_y \geq 227.9$
6	Colloidal stability for drilling mud	$4500\mu_p - \tau_y \geq -23.1$
10	Avoid high gel strength to prevent fluid loss	$\theta_T \approx \tau_y \leq 279.4$

Calculations for the third section:

- Depth: H=5150 ft
- Penetration rate: Vm= 0.12934 ft/min
- Mud density: $\rho_m = 75.34 \text{ lb/ft}^3$
- Flow rate: Q= 13012 lbb/day

Table 5. Linear Equations for Relationship $\tau_y = f(\mu_p)$ at depth 5150 ft

No.	Describe the limitation	Mathematical relationship
1	Cuttings lift	$4.79\mu_p + 0.104\tau_y \geq 0.0471$
2	Avoid high surge pressure	$65.6\mu_p - 0.88\tau_y \geq -3.31$
3	Avoid high swap pressure	$\mu_p \geq 4756.2$
4	Avoid fluid loss during rotation	$6.37\mu_p + 5.32\tau_y \geq 468.9$
6	Colloidal stability for drilling mud	$4500\mu_p - \tau_y \geq -21.8$
10	Avoid high gel strength to prevent fluid loss	$\theta_T \approx \tau_y \leq 61.2$

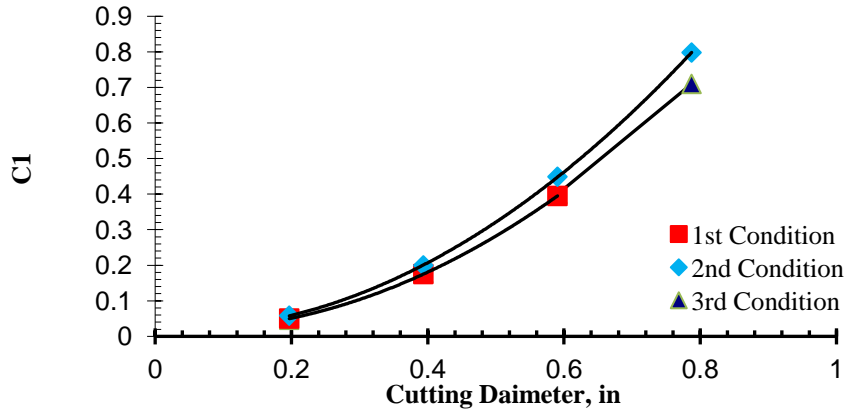


Figure 1. Graphical representation of the relationship $C_1=f(d_0)$

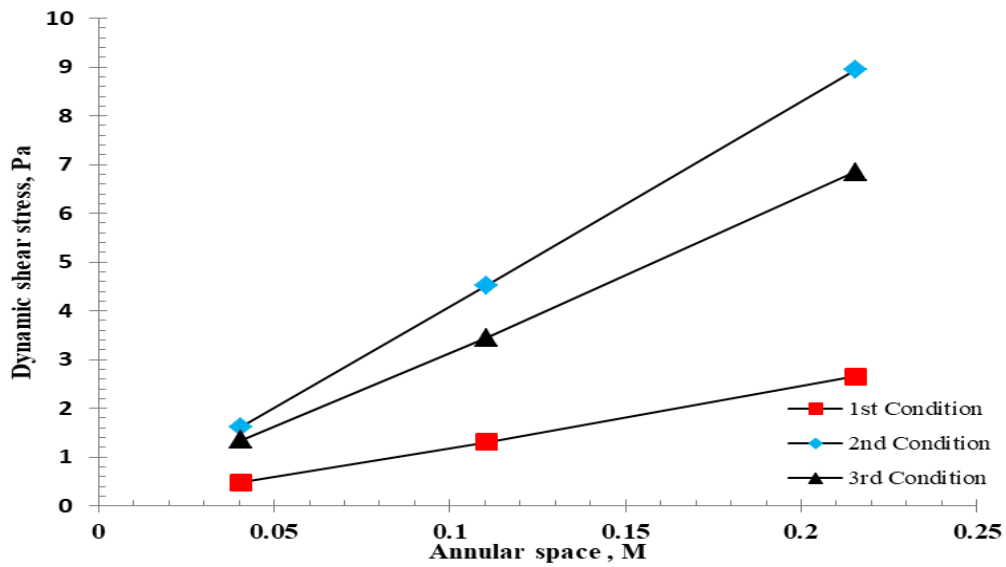


Figure 2. Graphical representation of the dynamic shear stress for different annular size

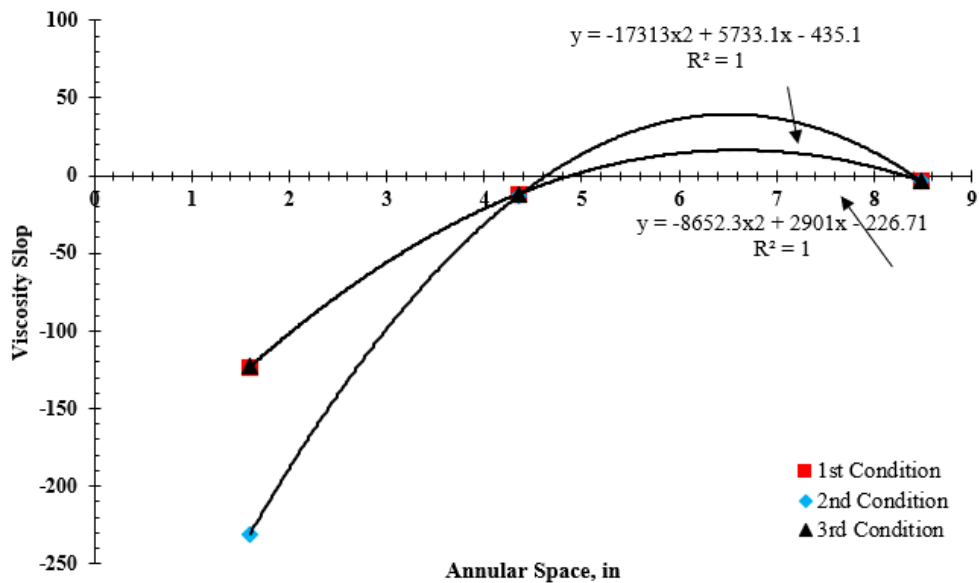


Figure 3. Graphical representation of the viscosity slop for different annular size.

4. Discussion

It was discovered that there is a significant difference between the results of such variables, making the work impossible to solve directly. On the one hand, due to the significant magnitude disparity, drawing the practical window on a single scheme (i.e. drawing all the restrictions) is challenging. As a result, the research focused on a small number of the most critical limitations, specifically three following points:

1. The second restriction is to avoid high surge pressure.
2. The fourth requirement is that to avoid fluid loss during rotation.
3. Colloidal stability for drilling mud is the sixth restriction.

We evaluated these limitations at three different cases with drilling speed, depth, and drilling bit diameter with an actual field data for each case separately (Table 3, 4, 5), and discovered that it is impossible to show all restrictions within the scale of one drawing, and that one restriction can replace another (Figure) and become the basis for closing the window from the top or bottom.

Figure 1 show that the cuttings diameter affected to the first limitation (cuttings lift) which refers to the constant C_1 and this constant increased with non-linearly increasing annular size but ability of drilling fluid for lifting cuttings decreased with decreasing C_1 .

Figure 2 show that as the dimensions of the annular space increase, the minimum required limits of the dynamic shear stress increase linearly and also vary according to the depth of the well and the properties of the drilling fluid, especially the density of this fluid.

5. Conclusions

In order to accomplish well target with less time and cost, well clean program should be found with significant research and analysis. Drilling fluid properties, drilling parameters and well geometric have been conducted and evaluated in this study. It has been analyzed the effect of diameter of drilling bit corresponding of the dimensions of annular space and drilling fluid properties. It is showed that the ability of drilling fluid to lift cuttings in a turbulent flow condition with increase the space of annular. Also, with increasing in space of annular dimension of the well, the viscosity values which determined by the restriction to avoiding high surge pressure due to lifting the drilling string decrease. This also shows in increasing in dynamic shear stress.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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