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Drilling Bit Hydraulics Optimization

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ABSTRACT

All drilling companies emphasize the importance of maintaining optimum drilling bit hydraulics in real-time drilling operations. The behavior of flow rate and pressure plays a crucial role in monitoring and optimizing drilling processes. By ensuring the hydraulic conditions are optimal, various drilling-related issues such as equipment failure, wellbore instability, and kicks can be minimized, resulting in significant time and cost savings. The paper's main objective is to illustrate the impact of mud pump flow rate optimization on the cutting Transport Fluid Velocity (TFV). This optimization directly influences the pressure loss inside the drill string and annular space, which, in turn, affects the selection of optimum nozzle sizes. The goal is to achieve efficient bottom hole cleaning and hole conditioning, ultimately leading to satisfactory rates of penetration (ROP). The study conducted a series of tests using different pump flow rates ranging from 100 to 500 gallons per minute (gpm) to drill two different sections. An 8 ½" bottom hole assembly (BHA) with a Tri-cone bit and a 6 1/8" BHA with a Polycrystalline Diamond bit were used. The WellPlane Software was employed for optimization. The results of the study indicate that for the 8 ½" section, a minimum pump rate of 488.3 gpm is necessary to avoid cutting accumulation and the formation of bed height. On the other hand, for the 6 1/8" section, a minimum pump rate of 193.2 gpm is required. The optimal parameters for achieving a bed height of zero in the 8 ½" section are a pump flow rate of 500 gpm and nozzle size of (316). For the 6 1/8" section, a pump flow rate of 250 gpm and nozzle size of (514) are recommended. In summary, the optimization of bit hydraulics is essential for mitigating drilling problems and reducing overall drilling costs. By maintaining proper flow rate and pressure conditions, along with appropriate nozzle sizes, efficient bottom hole cleaning can be achieved, leading to improved rates of penetration and overall drilling performance.

Keywords: Drilling, Bit, Hydraulics, Optimization, Bingham Plastic

التصميم الأمثل للعملية الهيدروليكية لرأس الحفر

إبراهيم سالم مسعود محمد

هندسة النفط ، كلية الهندسة صبراتة ، جامعة صبراتة ، صبراتة، ليبيا

ملخـــــــص البحـــــــث

يعد تأمين تصميم هيدروليكي مثالي لرأس الحفر عنصرًا أساسيًا لمراقبة عملية الحفر والتي تتأثر بتدفق السوائل وتغير الضغط. وتعتبر مشاكل مثل تعطل المعدات وانفجار الابار وعدم استقرار حفرة البئر مصدرًا مهمًا للمشاكل المتعلقة بسائل الحفر وبالتالي تزيد من الوقت الضائع وصرف اموال ليست ضمن المخطط له. علاوة على ذلك، فإن العمليات المثلى لتنظيف وتهيئة حفرة البئر فيما يتعلق بالتدوير الهيدروليكي لها اهمية كبيرة في تجنب الوقت الضائع. الهدف الرئيسي من هذا البحث هو توضيح تأثير تحسين معدل تدفق مضخة الطين على سرعة مائع نقل القصاصات (**TFV**). بمعنى آخر، يعد الحفاظ على فقدان الضغط الأمثل داخل عمود الحفر وفي الفراغ الحلقي، والذي يؤثر على حجم فتحات المخاريط الأمثل، عنصرًا أساسيًا في تحسين العملية الهيدروليكية اثناء عملية الحفر. ونتيجة لذلك، يتم تحقيق التنظيف الأمثل للبئر مما يؤدي إلى الهدف العام المتمثل في الحفاظ على معدل اختراق مرضي (**ROP**). تم استخدام سلسلة من معدلات تدفق لتصميم امثل لعملية التدوير الهيدروليكية الإجمالية للبئر تدرجت من (100 إلى 500) جالون في الدقيقة (**gpm**) لحفر مقطعين مختلفين باستخدام مجموعة حفر **BHA** بقطر **8 1/2** بوصة، معرأس حفر ثلاثي المخروط و**BHA** **6 1/8** بوصة مع رأس حفر من الالماس. تم إجراء التصميم باستخدام برنامج **WellPlane** وأظهرت النتائج أن الحد الأدنى لمعدل الضخ لتجنب تراكم القطع الذي يؤدي إلى تراكم القصاص الصخري للمقطع **81/2** هو 488.3 جالون في الدقيقة بينما للقسم **6 1/8** هو 193.2 جالون في الدقيقة. علاوة على ذلك، بالنسبة للمقطع **8 1/2**، فإن معدل تدفق المضخة 500 جالون في الدقيقة وحجم الفوهات (3*16) هو الأمثل لمنع تراكم القصاص. اما بالنسبة للمقطع **6 1/8** بوصة، يوصى بمعدل تدفق يبلغ 250 جالونًا في الدقيقة وحجم الفوهات (5*14). وبهذا نجد ان تحسين عملية التدوير الهيدروليكي لعملية الحفر في افضل تصميم أمرًا رئيسيا لتجنب معظم مشاكل الحفر وتقليل تكلفة الحفر الإجمالية.

الكلمات الدالة: رأس الحفر، سائل الحفر، التدوير الهيدروليكي، نموذج بينجهام

1. Introduction

Drilling hydraulic system design depends mainly on pressure drops calculation in all of the circulating system parts [1, 2]. Regardless pressure drop through the bit, all other pressure losses that are pressure drops inside and around the whole drill string are calculated. Several hydraulics slide rules are available from bit manufacturers for calculating annular pressure losses, owing to: (a) the fact that annular pressure losses are normally small and may be beyond the scale of the slide rule; and (b) the fact that annular pressures are frequently laminar in nature and most slide rules use turbulent flow models [1, 3].

Figure 1 shows the circulating system components, in drilling operations involving high volume rates, particularly those exceeding 1000 gallons per minute (gpm), the maximum surface pressure becomes a critical factor. To accommodate such high flow rates, it is common to utilize two pumps [1, 6]. On land rigs with well depths of approximately 12,000 feet, the surface pressure typically has limits ranging from 2,500 pounds per square inch (psi) to 3,000 psi. However, in the case of deep wells, heavy-duty pumps capable of providing pressures up to 5,000 psi are required to meet the demands of the operation.

The use of two pumps and the availability of high-pressure capabilities are necessary to maintain the required flow rates and effectively manage the drilling process at greater depths. By ensuring that the surface pressure remains within the specified limits, drilling operations can be conducted safely and efficiently.

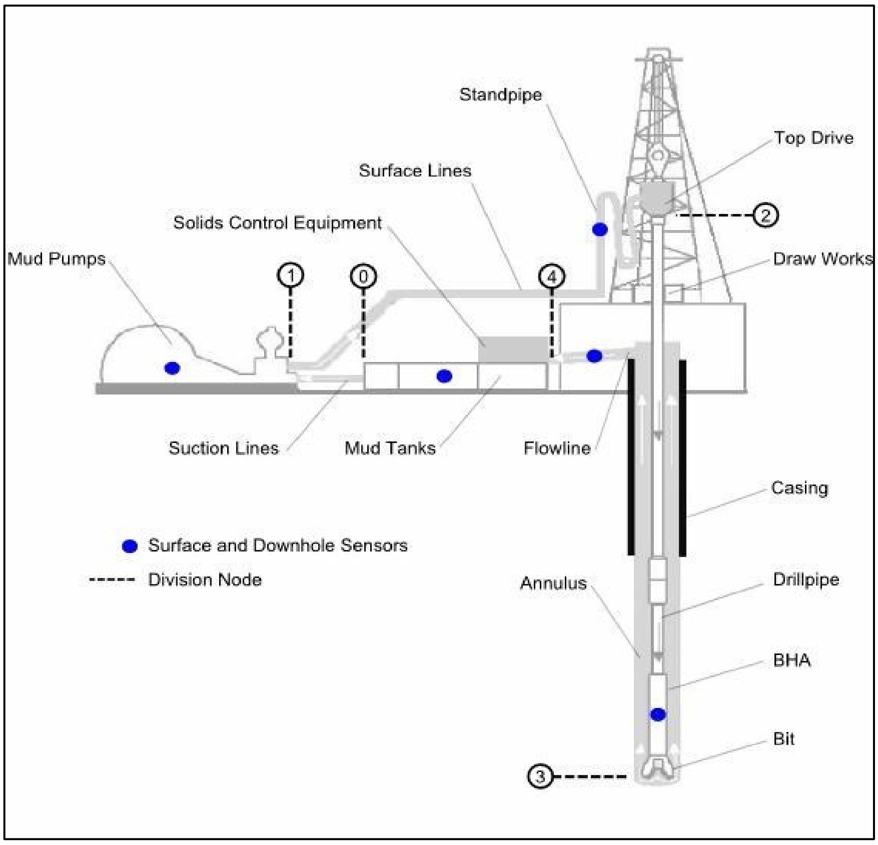

Figure 1. Mud circulation system [4, 5].

It is important to emphasize that these limitations on surface pump pressure must be taken into account when optimizing bit hydraulics in drilling operations [7]. The optimization process should consider the maximum surface pressure constraints to ensure safe and efficient drilling practices. By considering these limitations and optimizing bit hydraulics accordingly, drilling operations can be conducted with greater precision and effectiveness.

The two criteria commonly used for bit hydraulics optimization are the maximum bit hydraulic horsepower (BHHP) and the maximum impact force (IF) [8, 9]. These criteria yield different values for nozzle sizes due to variations in the bit pressure drop obtained from each criterion.

The choice between these criteria ultimately rests with the engineer overseeing the drilling operation. In many cases, the decision is influenced by the fixed rate of one of the criteria, typically the annular velocity. This means that only one variable, the pressure drop across the bit (Pbit), remains to be optimized. To optimize bit hydraulics, both criteria can be examined in detail, allowing for a comprehensive understanding of their implications. Additionally, a quick method for optimizing bit hydraulics can be offered [1, 9]. This method likely provides a practical and efficient approach to determining the optimal bit hydraulics configuration for a given drilling operation.

The study is carried out on a horizontal development well **(**EXXXH**-59)** in Gialo Field applying the following scenario:

26”, 17 ½”, 12 ¼” and 8 ½” pare hole sections are vertical, the 8 ½” pare hole will be plugged back, and the directional work will be at both 8 ½” main hole and 6 1/8” horizontal hole, as shown in Figure 2.

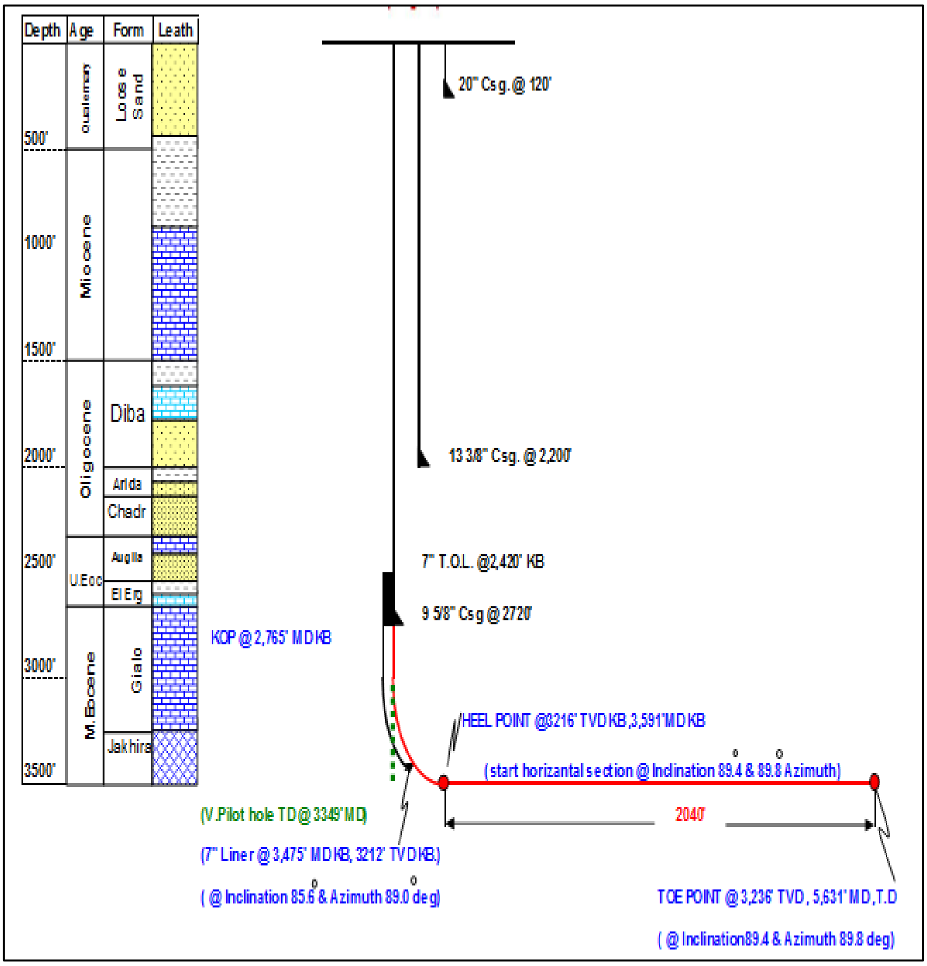

Figure 2. Well Profile and plan survey

The objective of this paper is to achieve an optimum bottom hole cleaning applying drilling hydraulics optimization to determine the optimum mud pump flow rate and optimum nozzle size using the Landmark Software.

2. Materials and Methods

2.1 WELLPLANE Soft ware:

The WellPlan Software is an efficient tool for well planning and drilling operation optimization analysis owned by Halliburton Company.

2.2 Well data:

Table 1: well data

Site-Block	**59, Horizontal Well**
Rig	NWD # 10
Surface geographical location	Lat. = 28° 42' 13.80" N Y = 3175287.0 m Long. = 21° 24' 29.92 E X = 539884.2 m
Target - Heel	Lat. = 28° 42' 13.88" N Y = 3175290.18 m Long. = 21° 24' 36.38" E X = 540059.38 m
Target - Toe	Lat. = 28° 42' 13.87" N Y = 3175292.0 m Long. = 21° 24' 59.29" E X = 540681.0m
Well Name	EXXXH-59
Well Type	Horizontal Development Well
Target Name	GIALO JAKHIRA LIMESTONE RESERVOIR
Target Depth (TVD), Displacement, Length, Azimuth, Inclination.	Heel=3216 ft TVD, Toe = 3236 ft TVD. Displacement; Heel= 575 ft and Toe= 2615 ft Azimuth = 89.8 Inclination = 89.4
WELL INTEGRITY	Quality cement bond for all casings from reservoir to surface.
Authorized Total Depth	TD = 5631 ft MD / 3236 ft TVD 2040 ft Horizontal into JAKHIRA LIMESTONE RESERVOIR.
Estimated Cost	$ x,xxx,xxx US$.
Estimated Days	Days: 45 Days
Ground Level	324 ft
RKB-GL	20 ft (Based on Rig NWD#10)
RKB-MSL	345.4ft

2.3 Hole Section: 8 ½'': BHA NO 1: From 2753 ft to 3506 ft.

Objectives: Side track 8.5 hole and drill curve with 14 deg /100 to reach 62 deg Inclination, toward 90 deg Azimuth as shown in Figure 3.

2.4 Hole Section: 6 1/8 '': BHA NO 2: From 3506 ft to 4670 ft.

Objectives: To drilling the 6 1/8" hole to landing point.

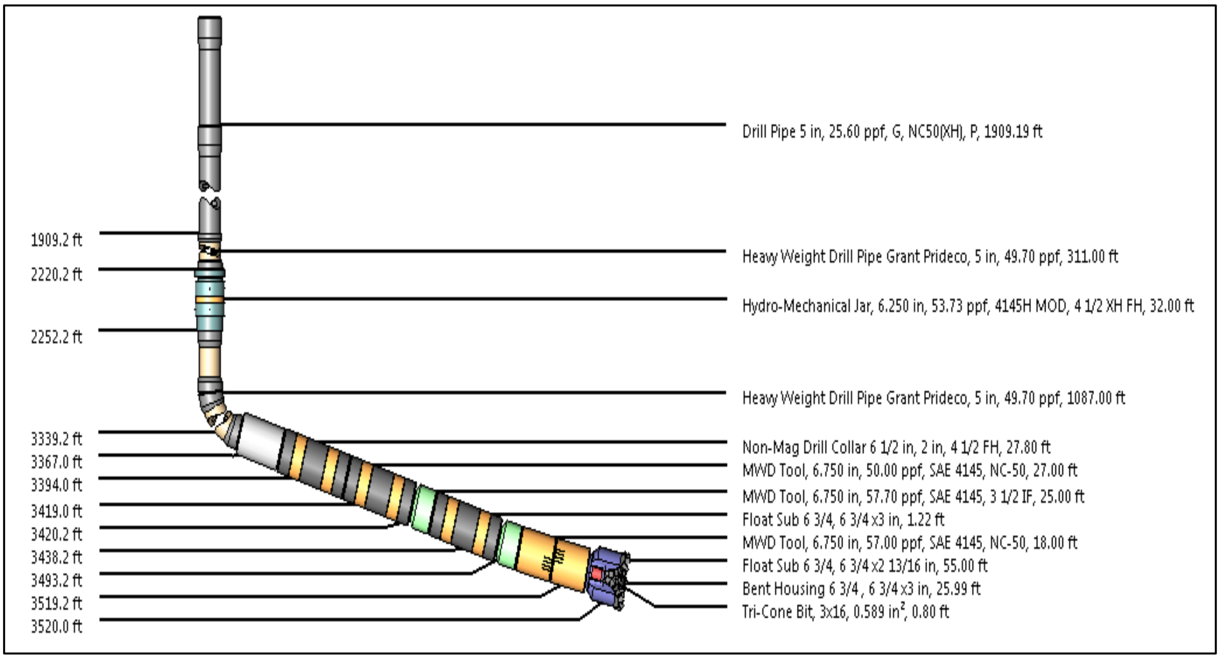

Figure 3. BHA used to drill 8 ½" hole

3. Theory and Calculation

3.1 Hydraulics module

The dynamic pressure losses in the circulating system can be simulated using Hydraulics module to provide analytical tools to optimize hydraulics. Several rheological models are provided such as Bingham Plastic, Newtonian, Power Law, Generalized Herschel-Bulkley, and Herschel Bulkley. The basis for the pressure loss calculations can be provided by selecting a rheological model [10, 11]. It can be chosen to optimize hydraulics based on maximum hydraulic horsepower, maximum impact force, maximum nozzle velocity, or percent pressure loss at bit. To get an accurate simulation design the latest simulation software should be used such as WELLPLAN Software.

3.1.1 The Bingham Plastic Module

The Bingham model is defined by the relationship:

$$Shear\ Stress\ =\ Yield\ Stress\ +\ (Plastic\ Viscosity\ x\ Shear\ Rate) \qquad (1)$$

The major difference between this and Newtonian fluids is the presence of a Yield Stress or "Yield Point" (which is a measure of the electronic attractive forces in the fluid under flowing conditions). No bulk movement of the fluid occurs until this yield stress is overcome. Once the yield stress is exceeded, equal increments of shear stress produce equal increments of shear rate.

As shear rate increases, the apparent viscosity decreases. This phenomenon is known as "shear thinning". A limit known as The Plastic Viscosity, which is a value of the apparent viscosity when shear rates approach infinity, [10, 11]. This viscosity is the slope of the Bingham plastic line, commonly used fan V-G meter to measure viscosities for this model.

$$\tau = YP + PV * \gamma \qquad (2)$$

Pressure Loss in pipe

IF $R_a > 2000$ $then$

$$P_a = \frac{0.0012084581(\rho^{0.75})(PV^{0.25})(Q^{1.75})L}{(D_H - Dp)^\wedge 1.25(DH^2 - Dp^2)^\wedge 1.75} \tag{3}$$

If Laminar flow, then

$$P_a = (0.05333)\left(\frac{Yp}{D_H - D_p}\right) + \left(\frac{(0.0008488263Pv*Q)}{\left(D_H - D_p\right)^2 *(D_H^2 - D_p^2}\right) * L \tag{4}$$

$$R_a = 1895.2796(\rho)\left(D_H - D_p\right)\left(\frac{Q}{(Pv(D_H^2 - D_p^2}\right) \tag{5}$$

$$V_{ca} = \frac{(2000 + PV_x) + R_a(\sqrt{PV^2 + 1.066(YP_x)(\frac{\rho}{g_c})\frac{D^2}{R_a}}}{2D*\frac{\rho}{g_c}} \tag{6}$$

$$h_p = \frac{QP_b}{1714} \tag{7}$$

Where:

D = Pipe inside diameter (ft), D_p = Pipe outside diameter (ft), D_H = Annulus diameter (ft)

τ = Shear stress (lb/100 ft^2), YP = Yield point (lb/100 ft^2), PV = plastic viscosity (cp)

γ = Shear rate (Sec^-1), R_a = Reynolds number, P_a = Pressure loss in annulus (lb/ft^2)

ρ = Weight density of fluid (lb/ft^3), Q = Flow rate (ft^3/sec), YP_x = Yield point (lb/ft^2)

L = Section length of pipe or annulus (ft), V_{ca} = Critical velocity in annulus (ft/sec)

PV_x = Plastic viscosity (lb sec/ft^2) = PV/47880.26, h_b = Bit hydraulic power (hp)

P_b= Pressure loss across bit nozzle, (psi), g_c = gravitational constant 32.17 ft/sec^2

3.1.2 The power Law module

The Power Law model assumes that all fluids are pseudoplastic in nature and are defined by the following equation [10, 11]:

$$\tau = K\,(\gamma)^{n^{n}} \tag{8}$$

Where:

τ = Shear stress (dynes / cm^2)

K = Consistency Index

γ = Shear rate (sec-1)

n = Power Law Index

$$n = 3.32Log(\frac{\theta_{600}}{\theta_{300}}) \tag{9}$$

$$K = \frac{\theta_{300}}{500^n} \tag{10}$$

The parameters 'n' and 'k' describe the fluids behavior and its degree of Non- Newtonian.

The constant "n" is called the POWER LAW INDEX and its value indicates the degree of non-Newtonian behaviour over a given shear rate range. If 'n' = 1, the behaviour of the fluid is considered to be Newtonian. As 'n' decreases in value, the behaviour of the fluid is more non-Newtonian and the viscosity will decrease with an increase in shear rate.

The "K" value is the CONSISTENCY INDEX and is a measure of the the thickness of the mud.The constant 'K' is defined as the shear stress at a shear rate of one reciprocal second. An increase in the value of 'K' indicates an increase in the overall hole cleaning effectiveness of the fluid. The units of 'K' are either lbs/100ft^2, dynes-sec, N/cm^2.

The constants n and K can be calculated from Fann VG meter data obtained at speeds of 300 and 600 rpm through use of equations Equation (9, 10).

Hence the Power Law model is mathematically more complex than the Bingham Plastic model and produces greater accuracy in the determination of shear stresses at low shear rates.

3.1.3 Herschel Bulkley

The Herschel-Bulkley (yield-power law [YPL]) model describes the rheological behavior of drilling muds more accurately than any other model using the following equation:

$$\tau = \tau o + (K \times (\gamma)^{n} \tag{11}$$

Where:

τ = measured shear stress in lb/100 ft^2

τ**o** = fluid's yield stress (shear stress at zero shear rate) in lb/100 ft^2

K = fluid's consistency index in cp or lb/100 ft sec^2

n = fluid's flow index

γ= shear rate in sec^{-1}

The Hole Cleaning Model is a mathematical model used to anticipate the minimum annular flow rates or velocities required to prevent or remove the formation of cuttings beds during directional drilling operations. It is based on the analysis of forces acting on the cuttings and their associated dimensional groups. The model predicts the minimum (critical) flow rate needed to prevent the formation of stationary cuttings. It has been extensively validated using experimental data and field data to ensure its accuracy and reliability. The Hole Cleaning Model evaluates the effects of various drilling variables on cuttings transport. These variables include cuttings density, cuttings load, rate of penetration (ROP), cuttings shape, hole size, mud density, deviation, mud rheology, drill pipe rotation rate, drill pipe size, flow regime, cuttings size, and mud velocity (flow rate). Using this model, engineers can analyze the impact of these variables on hole cleaning and predict the critical transport fluid velocity (CTFV). The CTFV represents the flow rate at which a cuttings bed will start to form in the annulus at the minimum flow rate. The model also allows for the calculation of bed height and cuttings volume based on the specified flow rate provided in the Transport Analysis Data [12, 13].

By considering the Hole Cleaning Model and its analysis of the drilling variables, engineers can optimize the drilling parameters to ensure effective cuttings transport and minimize the formation of cuttings beds in the annulus. This helps to maintain efficient drilling operations and avoid issues related to poor hole cleaning.

4. Results and Discussion

4.1 Hydraulics simulation analysis based on 8 ½'' BHA that has been used to drill this section.

From the results CTFV and inclination portions are independent of the specified flow rate. As shown in Figures 4, 5, and 6. The total cuttings volume will begin to become greater than the suspended cuttings volume in the well as a bed height is forming in that portion of the wellbore. When the CTFV for a portion of the well is greater than the flow rate specified in the Transport Analysis Data it will be noticed that the bed height begins to form. In order to prevent a cuttings bed from forming in that portion of the well, the specified flow rate must be increased to a rate greater than the CTFV flow rate.

4.1.1 Hydraulic cuttings transport

Figure 4 shows that 300 gpm pump rate is inadequate to maintain good bottom hole cleaning as the suspended cuttings volume is zero % of a total volume of about 18% with a bed height of 2.15 in. It is obvious that the minimum pump rate to get 0 bed height is 470.2 gpm.

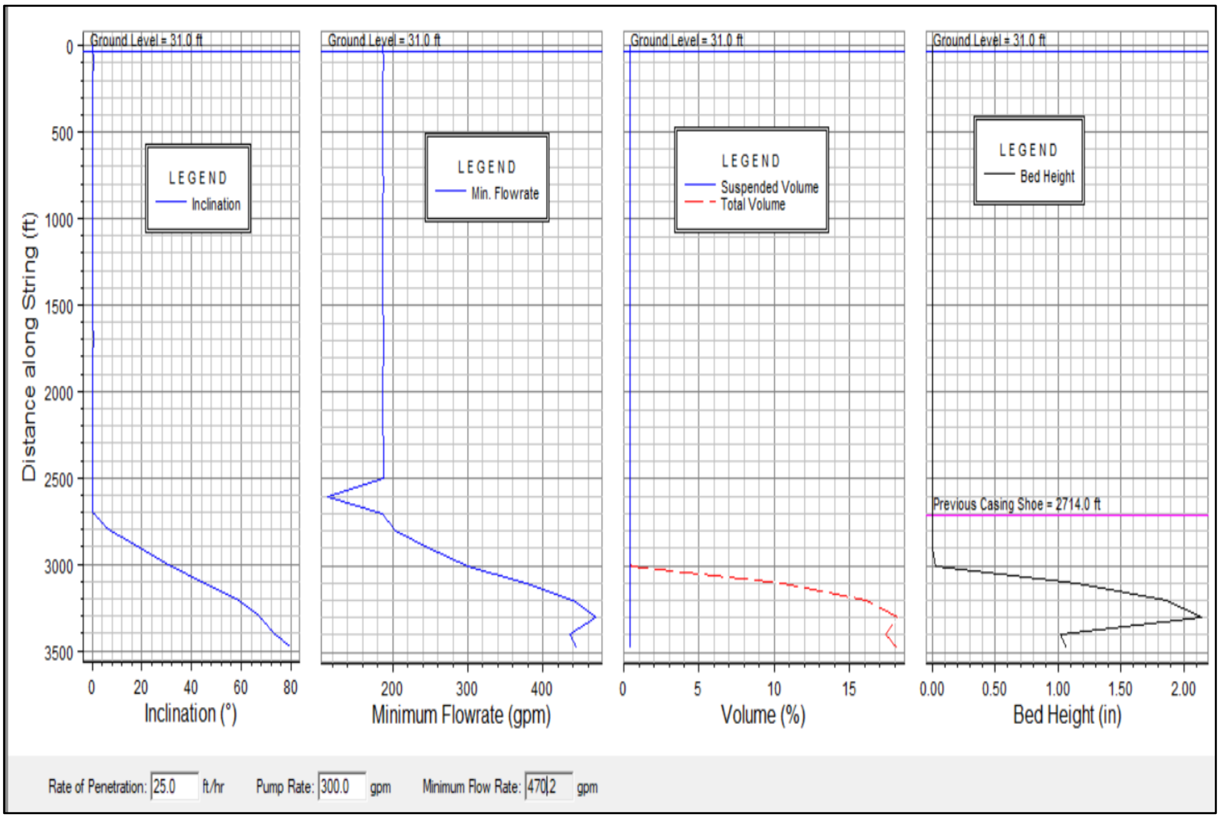

Figure 4. Cutting hydraulic transport at 300 gpm

However, when the pump rate increased to 500 gpm, Figure 5, the operation conditions come to be optimum as the minimum flow rate is 488.3. At 500 gpm the suspended volume would be identical to the total volume leading to a bed height of zero in.

4.1.2 Cuttings Total Volume change with flow rate change

From Figure 5 that shows the total volume percentage verses hole angle, it is obvious that at flow rate of 500 gpm the total volume is flatten at zero present whereas at lower flow rates it starts to increase from zero at different hole angels.

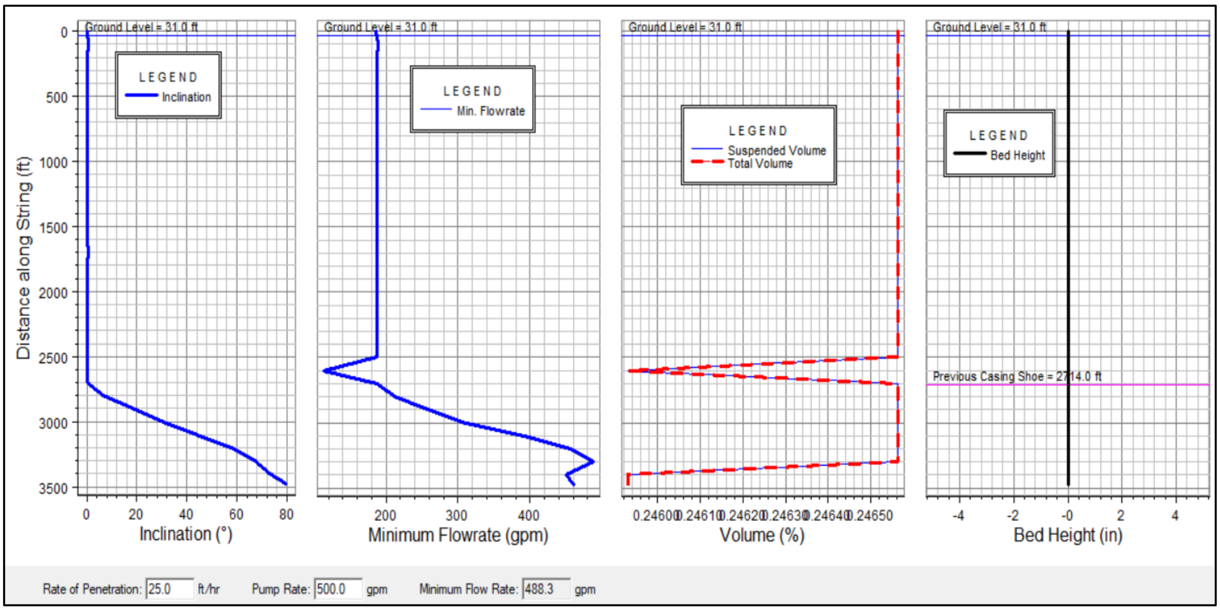

Figure 5. Cutting hydraulic transport at 500 gpm

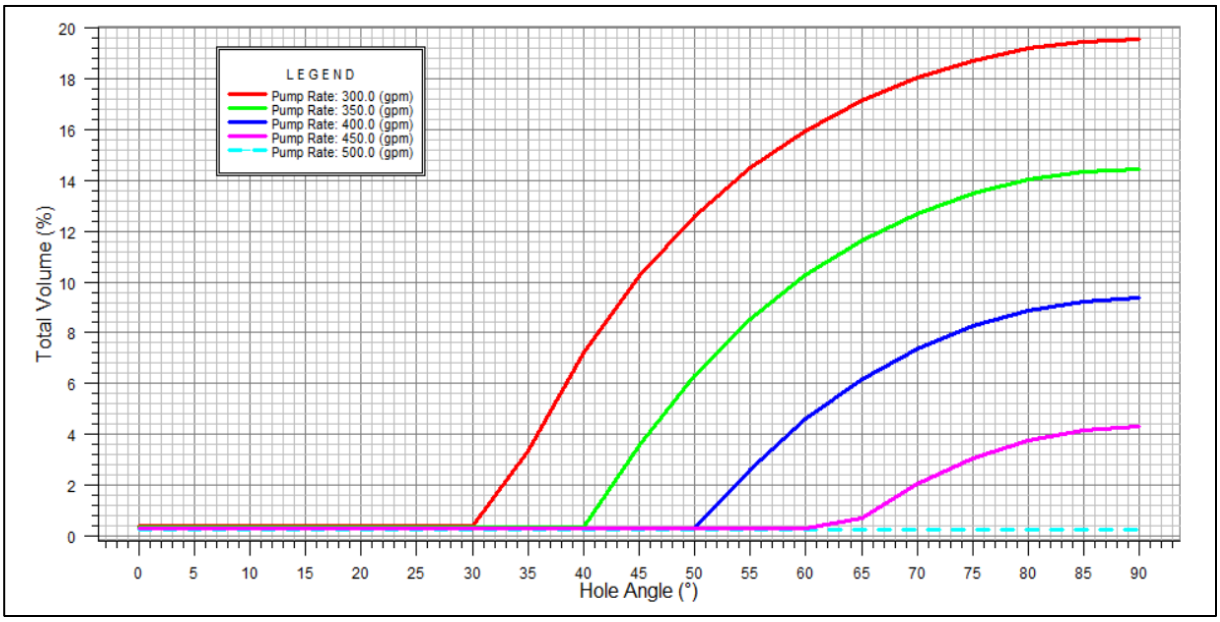

Figure 6. Cuttings Total Volume change with flow rate change, section 8 ½’’

Table 2 shows pressure loss and Minimum (critical) flow rates for a range of specified flow rates; it can be used to determine the flow regime, critical pump rate, annular velocity, and pressure loss for all annular cross-sectional areas.

Table **1**. 8 ½ BHA Hydraulic Optimization results

Flow Rate (gpm)	Measured Depth (ft)	Component	Hole OD (in)	Pipe OD (in)	Pressure Loss (psi)	Average Velocity (ft/min)	Reynolds Number	Critical Pump Rate (gpm)	Flow Regime
300	2278.3	Drill Pipe	8.755	5	64.72	142.4	300	725.9	LAMINAR
300	2589.3	Heavy Weight Drill Pipe	8.755	5	9.38	142.4	300	725.9	LAMINAR
300	2613.3	Mechanical Jar	8.755	6.75	1.36	236.5	751	465.5	LAMINAR
300	2714	Heavy Weight Drill Pipe	8.755	5	3.02	142.4	300	725.9	LAMINAR
300	3338.3	Heavy Weight Drill Pipe	8.755	5	18.91	142.4	300	725.9	LAMINAR
300	3366.3	Non-Mag Drill Collar	8.755	6.75	1.59	236.5	751	465.5	LAMINAR
300	3393.3	Logging While Drilling	8.755	6.75	1.53	236.5	751	465.5	LAMINAR
300	3418.3	MWD Tool	8.755	6.75	1.42	236.5	751	465.5	LAMINAR
300	3420.3	Float Sub	8.755	6.72	0.11	233.5	735	470.6	LAMINAR
300	3438.3	MWD Tool	8.755	6.75	1.02	236.5	751	465.5	LAMINAR
300	3448.3	Float Sub	8.755	6.72	0.56	233.5	735	470.6	LAMINAR
300	3475	Polycrystalline Diamond Bit	8.755	6.75	1.51	236.5	751	465.5	LAMINAR
350	2278.3	Drill Pipe	8.755	5	65.31	166.1	406	725.9	LAMINAR
350	2589.3	Heavy Weight Drill Pipe	8.755	5	9.48	166.1	406	725.9	LAMINAR
350	2613.3	Mechanical Jar	8.755	6.75	1.39	275.9	999	465.5	LAMINAR
350	2714	Heavy Weight Drill Pipe	8.755	5	3.05	166.1	406	725.9	LAMINAR
350	3338.3	Heavy Weight Drill Pipe	8.755	5	19.11	166.1	406	725.9	LAMINAR
350	3366.3	Non-Mag Drill Collar	8.755	6.75	1.62	275.9	999	465.5	LAMINAR
350	3393.3	Logging While Drilling	8.755	6.75	1.56	275.9	999	465.5	LAMINAR
350	3418.3	MWD Tool	8.755	6.75	1.45	275.9	999	465.5	LAMINAR
350	3420.3	Float Sub	8.755	6.72	0.11	272.4	978	470.6	LAMINAR
350	3438.3	MWD Tool	8.755	6.75	1.04	275.9	999	465.5	LAMINAR
350	3448.3	Float Sub	8.755	6.72	0.57	272.4	978	470.6	LAMINAR
350	3475	Polycrystalline Diamond Bit	8.755	6.75	1.55	275.9	999	465.5	LAMINAR
400	2278.3	Drill Pipe	8.755	5	65.9	189.8	525	725.9	LAMINAR
400	2589.3	Heavy Weight Drill Pipe	8.755	5	9.58	189.8	525	725.9	LAMINAR
400	2613.3	Mechanical Jar	8.755	6.75	1.42	315.4	1276	465.5	LAMINAR
400	2714	Heavy Weight Drill Pipe	8.755	5	3.08	189.8	525	725.9	LAMINAR
400	3338.3	Heavy Weight Drill Pipe	8.755	5	19.31	189.8	525	725.9	LAMINAR
400	3366.3	Non-Mag Drill Collar	8.755	6.75	1.66	315.4	1276	465.5	LAMINAR
400	3393.3	Logging While Drilling	8.755	6.75	1.6	315.4	1276	465.5	LAMINAR
400	3418.3	MWD Tool	8.755	6.75	1.48	315.4	1276	465.5	LAMINAR
400	3420.3	Float Sub	8.755	6.72	0.12	311.3	1250	470.6	LAMINAR
400	3438.3	MWD Tool	8.755	6.75	1.07	315.4	1276	465.5	LAMINAR
400	3448.3	Float Sub	8.755	6.72	0.58	311.3	1250	470.6	LAMINAR
400	3475	Polycrystalline Diamond Bit	8.755	6.75	1.58	315.4	1276	465.5	LAMINAR
450	2278.3	Drill Pipe	8.755	5	66.48	213.5	660	725.9	LAMINAR
450	2589.3	Heavy Weight Drill Pipe	8.755	5	9.67	213.5	660	725.9	LAMINAR
450	2613.3	Mechanical Jar	8.755	6.75	1.45	354.8	1580	465.5	LAMINAR
450	2714	Heavy Weight Drill Pipe	8.755	5	3.11	213.5	660	725.9	LAMINAR
450	3338.3	Heavy Weight Drill Pipe	8.755	5	19.51	213.5	660	725.9	LAMINAR
450	3366.3	Non-Mag Drill Collar	8.755	6.75	1.69	354.8	1580	465.5	LAMINAR
450	3393.3	Logging While Drilling	8.755	6.75	1.63	354.8	1580	465.5	LAMINAR
450	3418.3	MWD Tool	8.755	6.75	1.51	354.8	1580	465.5	LAMINAR
450	3420.3	Float Sub	8.755	6.72	0.12	350.2	1548	470.6	LAMINAR
450	3438.3	MWD Tool	8.755	6.75	1.09	354.8	1580	465.5	LAMINAR
450	3448.3	Float Sub	8.755	6.72	0.59	350.2	1548	470.6	LAMINAR
450	3475	Polycrystalline Diamond Bit	8.755	6.75	1.62	354.8	1580	465.5	LAMINAR
500	2278.3	Drill Pipe	8.755	5	67.07	237.3	808	725.9	LAMINAR
500	2589.3	Heavy Weight Drill Pipe	8.755	5	9.77	237.3	808	725.9	LAMINAR
500	2613.3	Mechanical Jar	8.755	6.75	1.48	394.2	1910	465.5	TURBULENT
500	2714	Heavy Weight Drill Pipe	8.755	5	3.14	237.3	808	725.9	LAMINAR
500	3338.3	Heavy Weight Drill Pipe	8.755	5	19.71	237.3	808	725.9	LAMINAR
500	3366.3	Non-Mag Drill Collar	8.755	6.75	1.73	394.2	1910	465.5	TURBULENT
500	3393.3	Logging While Drilling	8.755	6.75	1.67	394.2	1910	465.5	TURBULENT
500	3418.3	MWD Tool	8.755	6.75	1.55	394.2	1910	465.5	TURBULENT
500	3420.3	Float Sub	8.755	6.72	0.12	389.1	1872	470.6	TURBULENT
500	3438.3	MWD Tool	8.755	6.75	1.11	394.2	1910	465.5	TURBULENT
500	3448.3	Float Sub	8.755	6.72	0.61	389.1	1872	470.6	TURBULENT
500	3475	Polycrystalline Diamond Bit	8.755	6.75	1.65	394.2	1910	465.5	TURBULENT

4.1 Hydraulics simulation analysis based on 6 1/8'' BHA that has been used to drill this section

4.2.1 Hydraulic cuttings transport

Figure 7 shows that the minimum pump rate required to get 0 bed height is about 180 gpm. However, at the previous casing shoe a 193.2 gpm pump rate is required as minimum.

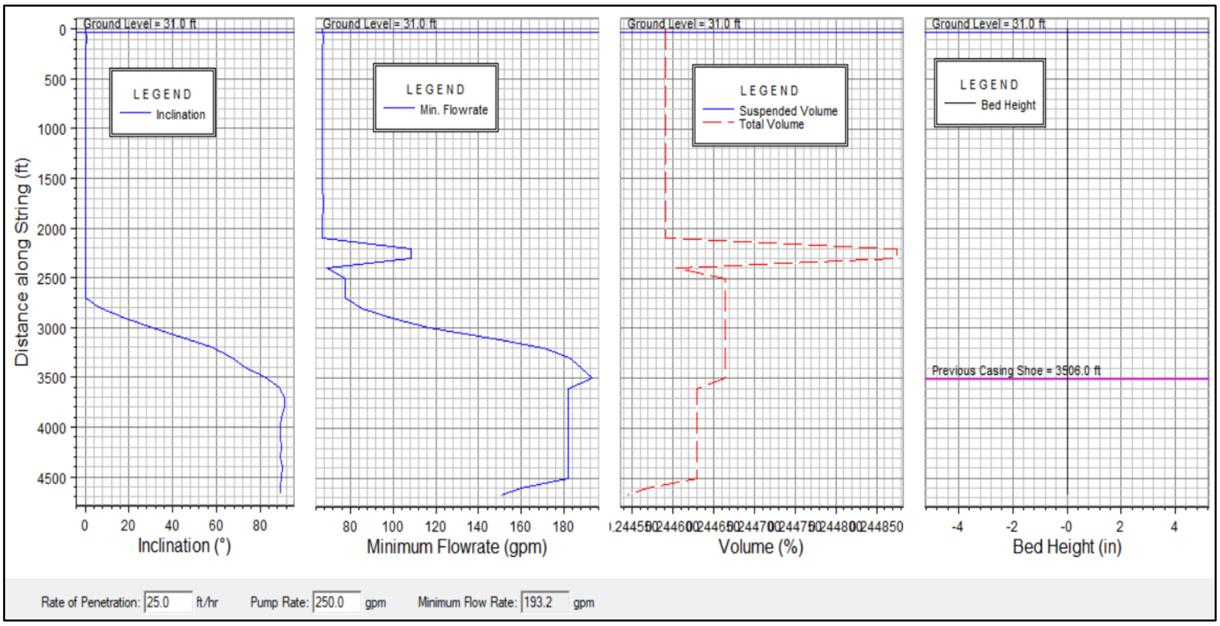

Figure 7: Hydraulic cutting transport, section 6 1/8"

4.2.2 Cuttings Total Volume change with flow rate change

Figure 8 shows that the total volume is flatten at zero present at the minimum flow rate and almost flattened at 180 gpm, whereas at lower flow rates it starts to increase from zero at different hole angels.

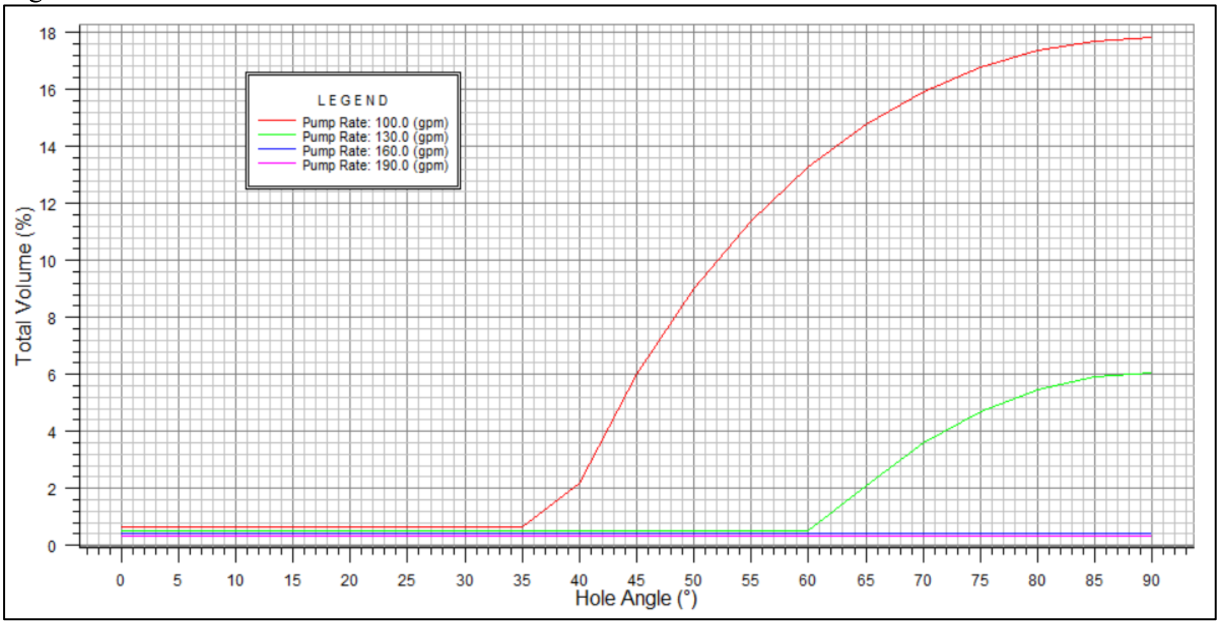

Figure 8: total cutting volume change with pump rate change, section 6 1/8"

5. Conclusions

In conclusion, the latest hydraulics simulation programs should be applied such as (WELLPLAN) before any drilling operation to avoid drilling problems that might happen such as low ROP, pack off, stuck, loss circulations, well bore breakouts, etc. Moreover, applying a proper hydraulic design minimizes drilling time and hence decreases the overall drilling cost. If bit hydraulics and bottom hole cleaning in both vertical and high inclination wellbores in water or oil base muds are inadequate that leads to regrinding of cuttings and reduces the ROP accordingly. The main optimization outcomes are that the minimum pump rate must be 488.3 and 193.2 gpm to drill an 8 1/2" section with Tri-con bit with (3*16) nuzzles size and 6 1/8" section with polycrystalline diamond bit with (5*14) nuzzles size respectively. Drilling following this optimization design guarantees a zero bed height which in turn increases the rate of penetration ROP.

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