Evaluation of drilling hydraulic calculation to the ability of bottom hole cleaning

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Abstract. In drilling operation there are two important matters that must be considered, which are the pumps and drilling fluid rheology that are influencing hydraulics drilling system. The major function of drilling fluid is to lift the drill cutting to the surface and still maintain the drilling hole to avoid an encounter. Evaluation of hydraulics drilling for bottom hole cleaning will count the parameter success which influence in removal of cutting to the surface for bottom hole cleaning and optimization drilling calculation hydraulics. The velocity of drilling fluid in annular, the flow that is formed and the ability of bottom hole cleaning are highly influenced by specifications of mud pump as a resource power for mud to flow that also will determine how the value of flow rate can be circulated. Mud rheology, PV, YP and MW will influence the performance of mud to carry cutting on drilling operation. The penetration to formation rock will make the broken bits of solid material removed from a borehole drilled by bit and resulting the drill cuttings. These cuttings could settle on the bottom of borehole so the main purpose of drilling fluid is to carry the cuttings to the surface, besides the drilling fluid also protecting borehole condition from any drilling problems. This evaluation is using Power Law Model for calculate pressure losses, drilling hydraulic optimization and also observe the parameter of Cutting Transport Ratio (Ft), Cutting Concentration (Ca), Carrying Capacity Index (CCI) and Particle Bed Index (PBI). The optimization results from Bit Hydraulic Horse Power (BHHP) method produce significant changes which are percentage horse power delivered to bit (%HHP) increasing to 53.17 – 54.79 % from actual condition which only ranges 5 – 51 %. Q optimum is very influential on the value of bit hydraulic horse power (BHHP) and surface horse power (HPS) that provide more optimized power to pump the mud with minimize the effect of pressure loss.

1. Introduction

Drilling mud will be circulated with mud pump to the bottom of the drilling hole so that the drill cuttings can be carried along with the flow of mud circulation to the surface. A good rheology and characteristics of mud will have the ability to bind cutting particles to rise along the flow of mud and also prevent the cutting to settle at the bottom of the borehole. The evaluation of cutting removal are done using the Moore Method, the Murchison Formula and the Power Law Model. The success of circulation hole cleaning analysis is using Cutting Transport Ratio (Ft), Cutting Concentration (Ca), Carrying Capacity Index (CCI) and Particle Bed Index (PBI) methods. While the method that is used to evaluate drilling, hydraulics is the Bit Hydraulic Horse Power Method (BHHP) using 4-5% KCL-Polymer mud in the well with a route of 8 ½".
2. Methods

The calculation of pressure loss in the circulation of drilling mud flow is important to know the optimal drilling design such as Pump Debit (Q), Nozzle Size, and Equivalent Cutting Density. Determination of laminar or turbulent flow patterns can be known with using the Average Velocity and Critical Velocity equations. Determining the flow pattern follows the following conditions [1].

1. If \( V' < V_{crit} \) then the flow is laminar
2. If \( V' > V_{crit} \) then the flow is turbulent

Total pressure loss system is the sum of pressure losses in surface equipment, pressure loss in the inside diameter of drill string, pressure loss in the annulus and loss of pressure in bits.

Cutting Transport Ratio \((F_t)\) is the best parameter to describe the cutting capacity of cutting removal by mud. Cutting Transport Ratio \((F_t)\) which has positive value then the drill powder will be lifted to the surface. The existence of Slip Velocity \((V_{slip})\) makes the cutting has a slower speed than the Mud Velocity in the Annulus \((V_{ann})\). According to Bourgoyne, Cutting Velocity in Annulus \((V_{p})\) [2] can be calculated as follows.

\[
V_{p} = V_{ann} - V_{slip} \quad (1)
\]

\[
F_t = \frac{V_{ann} - V_{slip}}{V_{p}} \times 100\% \quad (2)
\]

The Cutting Concentration \((C_a)\) is influenced by the Rate of Penetration \((ROP)\). According to Millpark, this parameter is important in determining cutting conditions. The Cutting Concentration \((C_a)\) above 5% in the annulus will cause a high torque problem, a decrease in the penetration rate and the pinch of the drill string.

\[
C_{a} = \frac{(ROP) \times \text{HoleSize}^{2}}{14.7 \times F_t \times Q} \times 100\% \quad (3)
\]

According to Van Dyke, to get a good picture of how does the drilling mud work for bottom hole cleaning then the other method that can be used is Cutting Carrying Index \((CCI)\). CCI is an empirical relationship of an actual data which equation is as follows [3].

\[
CCI = \frac{(K \times V_{ann} \times MW)}{400000} \quad (4)
\]

CCI \(\leq 0.5\) indicates bad hole cleaning and hole problems may occur. CCI \(\geq 1.0\) indicates a good hole cleaning.

Ziedler formulated a comparison of time between cutting settling with the travel time of cutting to the surface as the Drill Cutting Deposition Index \((\text{Particle Bed Index})\) calculated by the equation as follows [4].

\[
PBI_{\text{laminar}} = \frac{1}{12} \left( \frac{\text{HoleSize} - D_{pipe}}{V_{ann} - V_{slip}} \right) \frac{L_{cut} \times V_{slip} \times D_{radial}}{V_{ann}} \quad (5)
\]

\[
PBI_{\text{turbulent}} = \frac{V_{ann}}{17 \times V_{slip} \times \text{gravitasi}} \quad (6)
\]

PBI > 1 Cutting disposition does not occur.
PBI = 1 Cutting in almost settling conditions.
PBI < 1 Cutting has been deposited.
Hydraulics optimization in bits involves the loss of pressure in bits. The amount of pressure loss in the bit (PLossBit) is limited by the Maximum Pump Power and the Maximum Pump Pressure available on the surface. BHHP method optimization is commonly used because it suits to most conditions in the field. The definition of BHHP is maximizing the power used in bits from the Horse Power pump available on the surface. The principle is that the greater the power given by drilling fluid on the rock formation the greater the cleaning effect of the hole cleaning will be.

The steps for the Bit Hydraulic Horse Power (BHHP) optimization method are as follows.

\[
AN = \sum \frac{1}{4} \pi D^2 \quad (7)
\]

\[
PLossBit = \left(9.22 \times 10^{-5}\right) \times \frac{Q_{SPR}^2}{AN^2} \times MW \quad (8)
\]

\[
P_c = P_{SPR} - PlossBit \quad (9)
\]

\[
n = \frac{\log \left(\frac{P_c}{P_2}\right)}{\log \left(\frac{Q_1}{Q_2}\right)} \quad (10)
\]

\[
K_{loss} = \frac{P_c}{Q_{SPR}} \quad (11)
\]

\[
P_{BHHP} = \frac{n}{n+1} \times P_{stndpipe} \quad (12)
\]

\[
PLossBit_{optimum} = \frac{n}{n+1} \times P_{stndpipe} \quad (13)
\]

\[
AN = 0.0096 \times Q_{aktual} \times \sqrt{MW/P_{BHHP}} \quad (14)
\]

\[
DN = \left(\frac{4 \times AN}{3\pi}\right) \times 32 \quad (15)
\]

Range between 0 - 0.3 then the size of the nozzle is \(\frac{AN}{32}; \frac{AN}{32}; \frac{AN}{32}\). Range between 0.3 - 0.55 then the size of the nozzle is \(\frac{AN}{32}; \frac{AN}{32}; \frac{AN+1}{32}\). Range between 0.55 and so on then the size of the nozzle is \(\frac{AN}{32}; \frac{AN+1}{32}; \frac{AN+2}{32}\).\]

\[
P_{optimum} = P_{stndpipe} - P_{LossBit_{BHHP}} \quad (16)
\]

\[
Q_{optimum} = \left(\frac{P_{optimum}}{K_{loss}}\right)^{1/2} \quad (17)
\]

\[
BHHP = \frac{Q_{opt} \times P_{BHHP}}{1714} \quad (18)
\]

\[
HPS = \frac{Q_{opt} \times P_{stndpipe}}{1714} \quad (19)
\]

\[
HHP_{optimum}(\%) = \frac{HPS_{BHHP opt}}{HPS_{Optimum}} \times 100\% \quad (20)
\]

\[
HHSI_{optimum} (\text{inch}^2) = \frac{HPS_{BHHP opt}}{\pi (\text{HoleSize})^2} \quad (21)
\]

\[
TFA_{optimum} (\text{inch}^2) = \left(\frac{MW \times Q_{optimum}^2}{10858 \times P_{LossBit_{optimum}}}\right)^{0.5} \quad (22)
\]

3. Result and discussion
The calculations are carried out per depth of each trajectory according to the actual data from the drilling daily report (DDR). The following is data from the X well.
Table 1. Well summary.

| Hole Section | From – To (FT) | Casing (FT) | Days |
|--------------|---------------|-------------|------|
| 8 ½”         | 1521 – 3903   | 7” @ 3896   | 9    |

| Date         | MW | PV | YP | Funnel | Visco |
|--------------|----|----|----|--------|-------|
| 7-Sep-08     | 9.25 | 9.5 | 11 | 2          | 40    |
| 8-Sep-08     | 9.25 | 10.5 | 12 | 2          | 40    |
| 9-Sep-08     | 9.3  | 14   | 18.5 | 2          | 46    |
| 10-Sep-08    | 9.3  | 14.5 | 20 | 2          | 45    |

| Date         | Depth Drilling Report | ROP | RPM | Dcut |
|--------------|-----------------------|-----|-----|------|
| 6-Sep-08     | 1521                   | 0.08 |     |      |
| 7-Sep-08     | 2319                   | 0.08 |     |      |
| 8-Sep-08     | 3423                   | 0.08 |     |      |
| 9-Sep-08     | 3751                   | 0.08 |     |      |
| 10-Sep-08    | 3903                   | 0.08 |     |      |

On the drilling 8 ½” trajectory, the type of bit used is polycrystalline diamond compact bits with eight nozzles.

Based on the results of pressure loss system can be seen that the amount of pressure loss is high. This means that the pressure needed to circulate the mud flow is also large and the pressure channeled to the bit decreases. This will affect the amount of hydraulic power in the bit so that the amount of the hydraulic horse power bit is small. The BHHP method assumes that to maximize the effect of cutting cleaning then the power supplied in the circulation of sludge must also be optimum. Optimization begins with using the pump pressure and discharge data at the slow pump rate test so that the power of factor and the pressure loss constant are obtained. Then after obtaining the optimum conditions, the analysis cutting removal of is done using the optimization results. The following are the results of calculations from optimization using the Bit Hydraulic Horse Power (BHHP) method.

Based on the results of the optimization it can be seen that the value of the power channeled to the bit is much greater than in the actual condition. This result is very good if you want a clean condition at the bottom of the borehole. The size of the nozzle diameter also affects the jet velocity on the bit so that it can help clean the bottom of the hole and also erode the drill formation. 8 ½" trajectory to 3903 ft depth was successfully carried out without any obstacles. On the depth of 2066 ft-MD there is a penetration of Telisa formation which is dominated by clay so that it is shally water sensitive then 4-5% KCl is used for clay inhibition while to supports rheology with Duovis and Polypac-R, also the addition of Soltex for shale stabilizer. On the depth of 3681 ft-MD there is a penetration of Telisa formation and Besakap formation, which are claystone with stringer of limestone then sodium bicarbonate (NaHCO₃) is added to reduce contamination by calcium ions (Ca+2).

The actual condition of the value of pressure loss is quite large, this affects a lot on the bit hydraulic horse power (BHHP). At 2319 - 2903 ft-MD the value of pressure loss was 78.04 - 311.19 psi. This condition is due to the pump discharge value and the total flow area of the bit used. Basically, the ability of the pump to put pressure on the circulation system will be exhausted to overcome the pressure loss in the entire circulation system, though the bit pressure loss is the decisive parameter in the optimization calculation. Bit pressure loss is the amount of spent pressure to grind formation rock with a jet fluid from the bit nozzle.
Figure 1. Comparison of actual hydraulics calculations with optimization results in X well.

From the results of drilling hydraulics in actual conditions can be seen the amount of power that reaches the bits is very small, especially in drilling operations on the 8 ½" trajectory. The value of %HHP is below 20% so optimization is needed especially on bit pressure to have better parameters.

On the 8 ½" trajectory X well optimization, the very good results are showed. In actual conditions the flow pattern in the annulus formed tends to be turbulent in all drill string series, after optimization the flow pattern in the annulus changes to laminar. This result is very good because to lift the cutting it needs a straight up flow so that the cutting particles are carried become more stable in one direction towards the surface. After optimization at the depth of 2319 ft-MD, all flow patterns in the annulus change to laminar. This change has a big effect on the value of the particle bed index (PBI). The value of the particle bed index (PBI), which in actual conditions shows the tendency of precipitation (PBI less than one) has changed to a value of one so that the cutting does not settle in the annulus. Similarly, at the depth of 3423 ft-MD, flow patterns in annulus have changed some of not good conditions at the cutting transport ratio (Ft) and particle bed index (PBI) in actual conditions, with the value of optimum mud flow discharge changes from optimization calculations then the cutting removal gets better.

The optimum flow rate of the pump is 373.05 - 648.23 GPM. After doing the optimization calculation, the results of the comparison of hydraulic power in bits and hydraulic power on the surface show good results that can be seen from the calculations in each depth of the trajectory has a result that is much greater than the actual conditions. The actual BHHP value of the X-well ranges from 22.25 - 92.37 HP, while the optimization BHHP ranges from 65.52 - 233 HP. The optimization results make the power channeled from the mud pump to bits much larger which after the result is 53.17 - 54.79% compared to the actual channeled only 5 - 51%. Pump power channeled after optimization is also more stable compared to actual conditions which fluctuate at each depth.

The results show good parameters at each drilling depth. The pump discharge will affect the speed in the annulus so that it affects the flow pattern in the annulus. At Cutting Transport Ratio (Ft) of 88.78 - 97.18% with optimization of 91.19 - 96.90%, Cutting Concentration (Ca) is 0.23 - 0.25% with optimization 1.08 - 1.50%, Cutting Carrying Index (CCI) of 3.37 - 6.9 with optimization 0.99 - 6.16, and the Particle Bed Index (PBI) of 0.62 - 1.10 with optimization 0.67 - 1. The flow pattern formed influences the success of cutting removal. However, seeing the lithology in the X well flow pattern in annulus tends to be laminar so that it does not result in caving or wash out on the wall of the borehole.
formed. On the 8 ½” trajectory, the flow pattern in the annulus formed tends to be turbulent even though some points are laminated. However, the turbulent flow pattern makes the cutting removal are better although enlarge the possibility to cause a caving.

Compared to previous experiments that have been carried out on references from a study on the mechanism of bottom hole hydraulic pulse increasing drilling rate and reference from drilling hydraulics optimization using neutral networks, in accordance with these principles. The efficiency of drilling increases as the value of bottom-hole hydraulic pulsation increases, but it will decrease as the depth increases. And the difference between nozzles’ diameter and cone bit results in coexistence of both high-pressure region and low-pressure region and arouse hydraulic pulsation in bottom-hole flow field, which can increase ROP. As the difference between nozzles’ diameter increases, the value of bottom-hole hydraulic pulsation increases, thus, larger efficiency of drilling is achieved.

4. Conclusions

- Mudflow Discharge Optimum (Qoptimum) obtained from the optimization results is 373.05 - 648.23 GPM for 8 ½ “trajectory Wells X which greatly affect the value of bit hydraulic horse power (BHHP) and surface horse power (HPS).
- Optimization with the Bit Hydraulic Horse Power (BHHP) method resulted in a very significant increase in BHHP with changes in 22.25 - 92.37 HP to 65.52 - 233 HP.
- The amount of Surface Horse Power (HPS) has changed to 130.59 - 407.21 HP so that the ratio of power channeled to bits (% HHP) far increases by 53.17 - 54.79% compared to actual conditions which only range from 5 - 51%.
- The X well on the 8½” trajectory, the bit pressure is lost at 311 psi, the pressure loss on the surface equipment is 217.15 psi, the pressure loss in the drill inside diameter is 364.78 psi, the annular loss is 71.08 psi so that the total pressure loss which reads on the standpipe of 964 psi.
- The calculation results for optimization of the Transport Cutting (Ft) Ratio of 91.19 - 96.90%, Cutting Concentration (Ca) of 1.08 - 1.50, Cutting Carrying Index (CCI) of 0.99 - 6.16, and Particle Bed Index (PBI) of 0.67 - 1. These parameters are not much different from the actual conditions, but in the optimization, conditions result in a better dominance of the laminar flow pattern in lifting the cutting than the turbulent flow pattern.

The suggestion based on the results of the evaluation and optimization is the use of a new nozzle size in accordance with the results of optimization calculations that allow the beam produced from the nozzle hole to be more effective. In addition, the optimum pumping flow rate according to the optimization results will provide the Bit Hydraulic Horse Power (BHHP) of the mud pump power more optimally resulting in a reduced system pressure loss from the actual condition. The calculation of the evaluation and optimization of drilling hydraulics is expected to be a reference in subsequent drilling on similar wells.

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