CSCanada
Advances in Petroleum Exploration and Development
Vol. 14, No. 1, 2017, pp. 55-61
DOI:10.3968/9658

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Optimizing Hole Cleaning Using Low Viscosity Drilling Fluid

S. F. Ofesi[a],*; S. I. Onwukwe[b]; U. I. Duru[b]

[a]Department of Petroleum and Natural Gas Engineering, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.
[b]Department of Petroleum Engineering, Federal University of Technology, Owerri, Imo State, Nigeria.
*Corresponding author.

Received 10 June 2017; accepted 5 August 2017
Published online 26 September 2017

Abstract

When drilling for hydrocarbon, one most important thing to recognise is the bottom hole cleaning. Poor well hydraulics will lead to poor bottom hole cleaning. Several suggestions have been made in years back to prevent cuttings from falling to the lower side of the borehole thereby forming cutting bed. One of the main functions of drilling fluids is suspending the drill cuttings when the flow is static. But having met this criterion, cutting beds are still formed. The settling down of drill cutting makes this function of drilling fluid almost impossible. The formation of cutting bed due to the inability of the drilling fluid to establish this function brings about the objective of this research work. The main objective is to optimize hole cleaning using low viscosity drilling fluid and also to evaluate the effect of high flow rate on low viscous drilling fluid with respect to hole cleaning. This was carried out by a laboratory formulation of synthetic drilling fluid and the viscosity of this formulated fluid was varied from low to high. Tests for its rheological properties were carried out using Fann viscometer and the data obtained were recorded. The plastic viscosity and yield point were calculated from existing equations. The values for their rheological properties were tested using an existing hole cleaning model to determine the time taken for each of the drilling fluid to erode a 5 inches cutting bed. The fluid with an excellent hole cleaning value was also determined (*CCI* > or =1) and at optimum flow rate obtained for an 8-inches open hole section. When the values of their rheological properties were tested in the hole cleaning models, it was observed that, low viscosity fluids can erodes a 5 inches cutting bed height faster than the other drilling fluids and achieved an excellent hole cleaning value at an optimum flow rate when tested with the second model.

Key words: Fluid viscosity; Hole cleaning; CCI; Cutting bed; Erosion time

Ofesi, S. F., Onwukwe, S. I., & Duru, U. I. (2017). Optimizing Hole Cleaning Using Low Viscosity DrillingFluid. *Advances in Petroleum Exploration and Development*, *14*(1), 55-61. Available from: http://www.cscanada.net/index.php/aped/article/view/9658
DOI: http://dx.doi.org/10.3968/9658

INTRODUCTION

Good hole cleaning is the efficient and effective transport of drilled solid from the well bore to the surface. This facilitates the reasonable unhindered movement of tubular and drill strings. As hole angle increases, drilling cuttings settle by force of gravity along the lower portion of the hole, thereby forming cutting bed. As this bed is formed, any failure to achieve sufficient hole cleaning (i.e. clear off the bed) can cause severe drilling problems such as excessive over pull on trips, high rotary torque, stuck pipe, hole pack-off, excessive ECD (equivalent circulating density), formation break down, low rate of penetration and difficulty running casing and logs. The worst of this is sticking with the drill string. This can be very expensive to remedy. For the past years, the industry has been getting it wrong, that is why they have not been able to sufficiently clean the hole to avoid stuck pipe incident. In this study, to optimize hole cleaning, synthetic drilling fluid formulation was proposed as a base case. Its rheological properties like viscosity would be varied from low to high and its effect on hole cleaning obtained.

1. GENERAL REVIEW

Several works on hole cleaning have been carried out with different approaches. It is good to know that a clean hole for drilling is not a clean hole for tripping. Cuttings transport and efficient hole cleaning are indispensable in any drilling program. Cuttings are mobilized and suspended when the driving fluid forces acting on the solids are greater than the opposing gravitational and frictional forces. These forces are dependent on the area open to flow. In deviated wells, cutting settles on the lower side of the hole forming cutting bed. To erode this cutting bed, the study of hole cleaning which involves an understanding of the formation of cutting bed and the fluid rheological properties are required. In this part of this research, the existing works on hole cleaning are reviewed. The reviewed works include the mud rheology correlation method developed. The method proved that mud rheological parameters improved cuttings transport performance with the low–shear rate viscosity, especially the 6-rpm Fann V-G viscometer dial reading[1]. An experimental study to investigate cuttings bed erosion process under variable drilling fluid rheological properties and flow rates were conducted. From the experimental study, a model was developed to determine the cuttings bed erosion time in the annulus[2]. This was given by the following non-linear exponential model as

$$H_{(t)} = \alpha + \beta \, e^{-\gamma t}. \quad (1)$$

An experimental method, which investigated the influence of different variables in cuttings transport, such as hole angle, fluid rheology, cuttings size, drill pipe eccentricity, circulation ratio, annular size, and drill-pipe rotation using the concept of minimum transport velocity (MTV) was presented. The concept presumed that at lower minimum transport velocity (MTV), a wellbore would be cleaned more effectively[3]. The parameters affecting cuttings transport in the annulus for a vertical well which involved the construction of a simulation unit for cutting transport was carried out during an experiment. It was concluded that transport of small sized cuttings would increase, when drill-pipe rotation and drilling fluid density is high[4]. A study on flow-rate predictions for cleaning deviated wells was carried out to develop a prediction model for critical flow rate or the minimum flow rate required to remove cuttings from low side of the wellbore or to prevent cuttings accumulation on the low side of the annulus in deviated wells[5]. The model was proven by experimental data obtained from an 8 inch wellbore. During their study, a model and a computer program were developed to predict the minimum flow rate for hole cleaning in deviated wellbore. The model was later simplified into a series of charts to facilitate rig-site applications. Even with the applications of these models, hole cleaning still remains a major challenge. In a verge to reduce or completely do away with hole cleaning problems encountered in every drilling operation brings about this research work.

2. METHODOLOGY

2.1 Materials and Apparatus

In this study, the approach implored to Optimize hole cleaning using low viscosity drilling fluid was the laboratory formulation of three different drilling fluids. These were: (i) Base case. (ii) Low viscosity drilling fluid and (iii) high viscosity drilling fluid. The materials used in the formulation of these drilling fluids are shown in Table 1. The Apparatus used in the formulation are (i) the mud Mixer: This was used to stir the mixture together after each drilling fluid materials/additive was added. (ii) The Fann Viscometer: this was used to test for the rheological properties of the three drilling fluids. (iii) The Mersh Funnel: this was used to test for the drilling fluids viscosity. (iv) The Mud Balance: this was used to determine the weight (ppg) for each drilling fluid. The data obtained from the experiment were used with an existing hole cleaning model to evaluate the effectiveness of the three formulated drilling fluid on hole cleaning. After adding each material with their corresponding quantities into a mud mixer in the order shown in Table 1, it was stirred for 5 minutes. After all the materials were added, the mixture was stirred for 15 minutes to formulate a 1,080 ml volume of base case drilling fluid. The high viscosity drilling fluid was prepared, by dissolving 8.8 grams of 2.35 grams per milliliter of local clay into a set of 1,080 ml volume of already prepared base case drilling fluid in the mixing cup. The mixture was agitated for 15 minutes to form a high viscosity drilling fluid. The low viscosity drilling fluid was formulated from the already prepared 1,080 ml base case drilling fluid, by diluting 473 ml of 7.3 pound per gallon paraffin base oil into the base case drilling fluid in the mud mixer. The resulting mixture was agitated for 15 minutes

Table 1
Materials and the Quantities Needed for the Formulation of Base Case Drilling Fluid

S/*n*	Materials	Functions	Quantity
1	Base oil	Continuous phase	594 ml
2	$CaSO_4$	Primary emulsifier	18 ml
3	Lignite	Secondary emulsifier	9 ml
4	Lime $Ca(OH)_2$	Emulsion stabilizer	15 grams
5	Organophil clay	Viscosifier	18 grams
6	water/Cacl2	Brine	264 ml/90 grams
7	Barite	weighting agent	435 grams
8	Polyamide	wetting agent	3 ml
9	Fatty acid	Rheology modifier	3 ml
10	CMC	Fluid lost agent	9 grams
	Total volume		1,080 ml

2.2 Testing the Rheological Properties of Formulated Fluids

The rheological properties of the formulated drilling fluid were tested in the laboratory using Fan viscometer shear readings of 600 rpm, 300 rpm, 6 rpm, 3 rpm, and 10 minutes and 10 seconds Gel. The Plastic Viscosity and Yield Point were determined from the values of 600 rpm and 300 rpm shear readings of each of the drilling fluids.

2.3 Optimum Hole Cleaning Models

The approach implored in this study to evaluate the effectiveness of the three formulated drilling fluid on hole cleaning involved two models.

2.4 Robinson, (1993) Model

Robinson Model used the cutting carrying index (CCI)[1] to test excellent hole cleaning property at optimum flow rate for each drilling fluid using Equation (2):

$$CCI = \frac{K * AV * MW}{400000} . \quad (2)$$

To obtain the value of consistency index "k" the value of the flow behavior index "n" must be determined using Equation (3). The flow behavior index (n) can be determined as:

$$n = 3.322 \log\left(\frac{2PV + YP}{PV + YP}\right) . \quad (3)$$

The values of n can then be used to determine the value of k for the different drilling fluids using Equation (4).

$$k = 511^{1-n} (PV+YP) \quad (4)$$

Where:

n is the flow behavior index, K is the fluid consistency index, PV is the plastic viscosity (mPa.s), YP is the yield point (1b/100ft^2)

With the values of "k" obtained above, the Cutting Carrying Index (CCI) of Robinson model was calculated.

2.5 Noah (2013) Model

This model uses a non-linear exponential equation to solve for the rate of cuttings bed erosion in the annulus[2]. The model is given by Equation (5) as:

$$H_t = (\alpha + \beta e^{-\gamma t}) . \quad (5)$$

Where,

α= Residual bed height (bed height corresponding to infinite circulation time)

β = Initial cuttings bed height - Residual bed height

K = fluid Consistency Index

$$\gamma = n/k . \quad (6)$$

With the values of inverse viscosity function "γ" for each drilling fluid obtained using Equation (6), the cutting bed erosion time for each drilling fluid was obtained as suggested by the model.

3. RESULTS AND DISCUSSION

Tables 2, 3 and 4 show the results from the rheological test carried out for the three drilling fluids. The Tables show the values obtained from the rheological test carried out for the three drilling fluids at shear rate of 600 rpm, 300 rpm, 6 rpm, 3 rpm, 10 minutes and 10 seconds gel and viscosity, plastic viscosity, yield point and Mud weight

Table 2
The Rheological Result for Base Case Drilling Fluid

Parameters	Values
Shear rateat 600 rpm	58
Shear rate at 300 rpm	39
Shear rate at 6 rpm	14
Shear rate at 3 rpm	12
Shear rate at 10'/10" Gel	12/14.
Viscosity	63 cp
Plastic viscosity	19 mPa.s
Yield point	20 1b/100ft2
mud weight	9.1 ppg

Table 3
The Rheological Result for Low Viscosity Drilling Fluid

Parameters	Values
Shear rate at 600 rpm	46
Shear rate at 300 rpm	30
Shear rate at 6 rpm	11
Shear rate at 3 rpm	8
Shear rate at 10'/10" Gel	8/11 Ibs/100ft2
Viscosity	46 cp
Plastic viscosity	16mPa.s
Yield point	14 Ib/100ft2
Mud weight	8.8ppg

Table 4
The Rheological Result for High Viscosity Drilling Fluid

Parameters	Values
Shear rate at 600 rpm	72
Shear rate at 300 rpm	50
Shear rate at 6 rpm	18
Shear rate at 3 rpm	15
Shear rate at 10'/10" Gel.	15/18.Ibs/100ft^2
Viscosity	91cp
Plastic viscosity	22 mPa.s
Yield point	28 1b/100ft2
MUD weight	9.4 ppg

Table 5 shows the variables and the summary of the results of the rheological properties of the three drilling fluid as suggested by Noah model. The fluid flow behavior index "n", fluid consistency index "k", the inverse viscosity function, the plastic viscosity, yield point and mud weight values for the three drilling fluids can be seen in Table 5 as well.

Table 5
The Summary of the Result of Drilling Fluids Rheology Properties Using Noah Model

Variables		Fluid types		
		Synthetic drilling fluid	**High viscosity drilling fluid**	**Low viscosity drilling fluid**
Drilling rheology parameters	Fluid flow behavior index “n”	0.2545	0.2614	0.2870
	Fluid consistency Index “k”	40.40	50.05	25.60
Inverse viscosity function “γ”	$\frac{n}{k}$	0.0063	0.0052	0.012
PV (cp)	$= \left(\text{Shear rate a 600 rpm} - 300\text{ rpm}\right)$	19	22	16
YP (Ib/100ft2)	$= \left(\text{Shear rate at 300 rp} - PV\right)$	20	28	14
MW (ppg)		9.1	9.4	8.8

Table 6
The Summary of the Result of Drilling Fluids Rheology Properties Using Robinson Model

Variables		Fluid types		
		Synthetic drilling fluid	**High viscosity drilling fluid**	**Low viscosity drilling fluid**
Drilling rheology Parameters	Fluid flow behavior index “n”	0.5725	0.5260	0.6166
	Fluid Consistency Index “k”	560.9	761	327.7
MW (ppg)		9.1	9.4	8.8

Table 6 shows the fluid flow behavior index “n”, fluid consistency index “k” and mud weight values for the three drilling fluids as suggested by Robinson.

According to Robinson, if CCI is equal to 0.5 or less, the hole cleaning is poor, but if CCI is equal to 1 or more, the hole cleaning is excellent[6]. From the results in Table 7, the CCI for low viscosity drilling fluid is 1.03, for the base case drilling fluid is 0.9 and for high viscosity drilling fluid is 0.8.

Table 7
The Summary of the Result for Cutting Bed Erosion Time (t), CCI, Optimum Flow Rate for Low Viscosity Drilling Fluid and ECD for Each Drilling Fluid

		Drilling fluid types		
		Base case drilling fluid	**High viscosity drilling fluid**	**Low viscosity drilling fluid**
Noah model for cutting bed erosion time. (min)	$t = -\frac{1}{\gamma}\ln\frac{(h\,(t) - \propto)}{\beta}$	563	644	199
Robinson model CCI at 490 gpm	$\frac{\text{K} * \text{MW} * \text{AV}}{400000}$	0.9	0.8	1.03
Optimum flow rate (gpm) for $CCI >$ or = 1	$CCI = \left(\frac{25.5}{400000} * \frac{k * MW * q}{d_h^2 - d_p^2}\right)$	570	630	490

When these three different fluids rheological properties were also substituted into the mathematical model of the time taken for cutting bed erosion[2], it was observed that the time taken to erode a 5 inches cutting bed height for low viscosity fluid was 199 minutes, for base case drilling fluid was 563 minutes and for high viscosity fluid was 644 minutes.

Recall that,

$$AV = \frac{25.4\,q}{d_h^2 - d_p^2}\,. \tag{7}$$

AV is annular velocity (ft/min), q is flow rate (gpm), d_h hole diameter (inches), d_p pipe diameter (inches).

Substituting equation 7 into 2 gives the relationship between flow rate “q” and CCI as shown in equation 8 as

$$CCI = \frac{0.0000635 * K * MW * q}{d_h^2 - d_p^2}\,. \tag{8}$$

Figure 1 show the relationship between Cutting Carrying Index, fluid Viscosity and Flow rate for the three drilling fluids in an 8 ½ inch open hole section. In every drilling operation, the rule of thumb for minimum and maximum advisable flow rate for open hole section is 355 gpm and 510 gpm. From Figure 1, it can be deduced that when the viscosity of the base case drilling fluid was reduced to form the low viscosity drilling fluid, the *CCI* and Flow rate graph shifted upward and when the viscosity was increased to form the high viscosity drilling fluid, the graph shifted downward. With the position of both base case and high viscosity drilling fluids, the variation of flow rate within the flow window (355 gpm and 510 gpm) cannot achieve an excellent hole cleaning values (*CCI* > or = 1). But an excellent hole cleaning values can only be achieved with low viscosity drilling fluid at a corresponding optimum flow rate as shown in figure 1. The linear relationship of this parameter is given in equation 8 above.

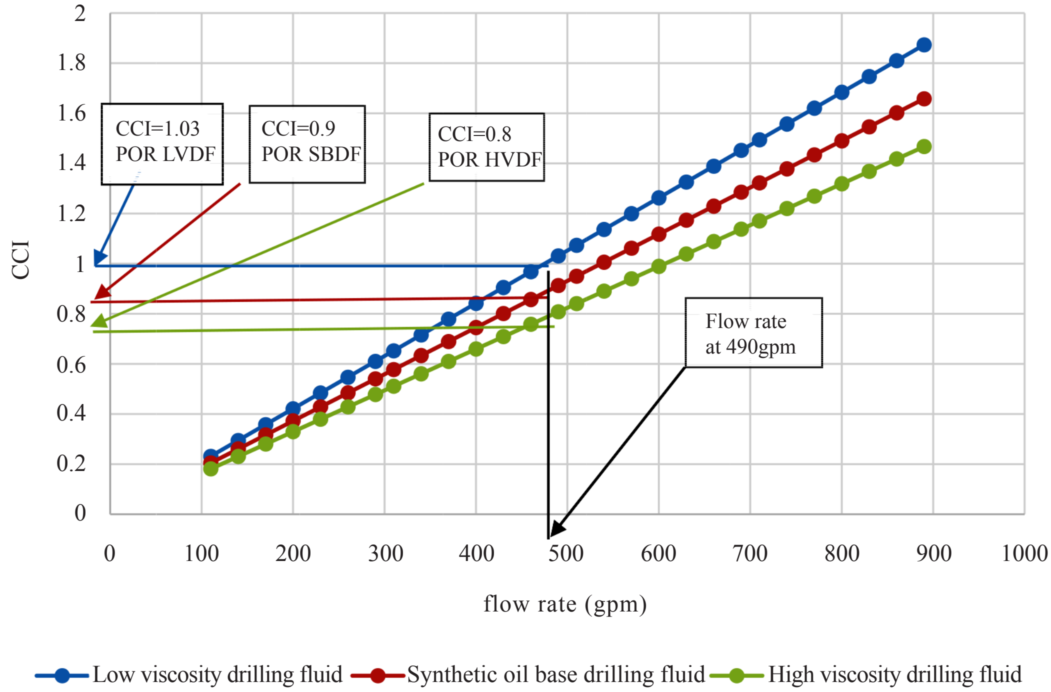

Figure 1
The Effect of Change in Drilling Fluid Viscosity, Flow Rate on *CCI*

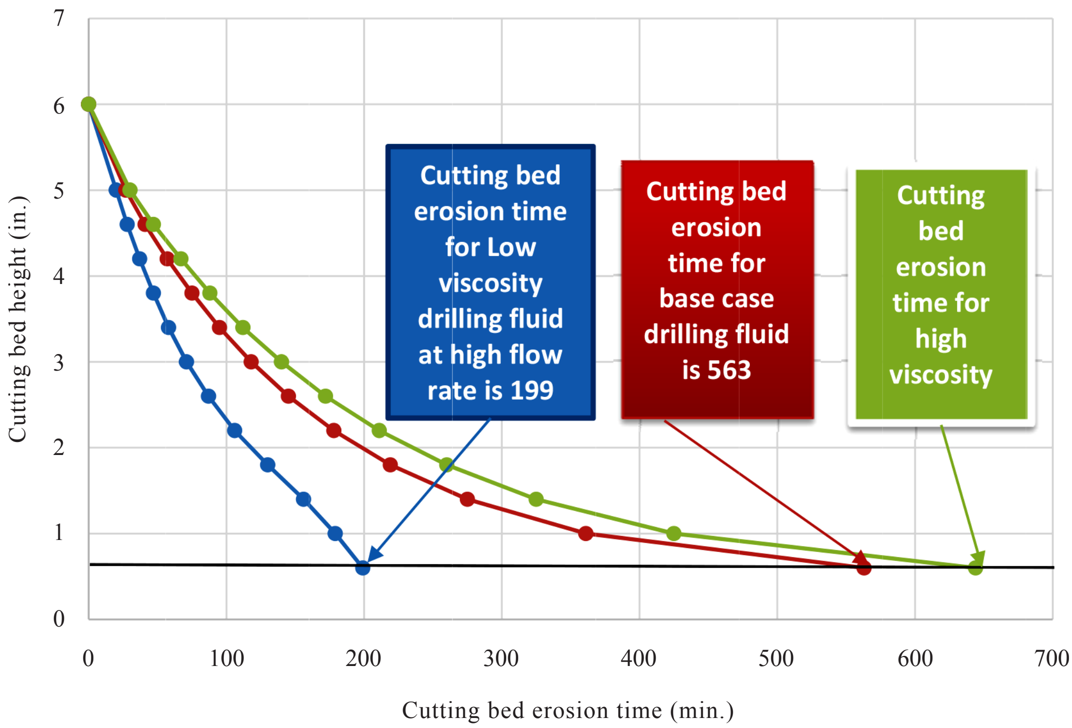

Figure 2
Cutting Bed Erosion Time for Three Drilling Fluids

Figure 2 is a graphical representation of result obtained from Noah's model. The graph shows the time taken (minutes) to erode a 5 inch. cutting bed. From the graph, it was observed that it took the low viscosity fluid 199 minutes to erode a 5 inch cutting bed to 0.6 inches while it took the base case drilling fluid 543 minutes and high viscosity drilling fluids 644 minutes to erode same cutting bed height. From this graph, it is clear that low viscosity fluid at high flow rate is very effective in eroding cutting bed faster. Equation (9) represents a linear equation for plotting Figure 2.

$$t = -\frac{1}{\gamma}\ln\frac{(h(t)-\propto)}{\beta}.$$

Figure 3 explains the effect the variation in drilling fluid viscosity may have on cutting bed erosion time.

The Figure show the effect of change in viscosity on cutting bed erosion time based on Noah model. From the Figure a decrease in inverse viscosity function "γ" (i.e an increase in viscosity) will result to an increase in cutting bed erosion time. On the other hand, an increase in inverse viscosity function "γ" (i.e a reduction in viscosity) will result to a decrease in cutting bed erosion time. The linear relationship can be seen in Equation (9).

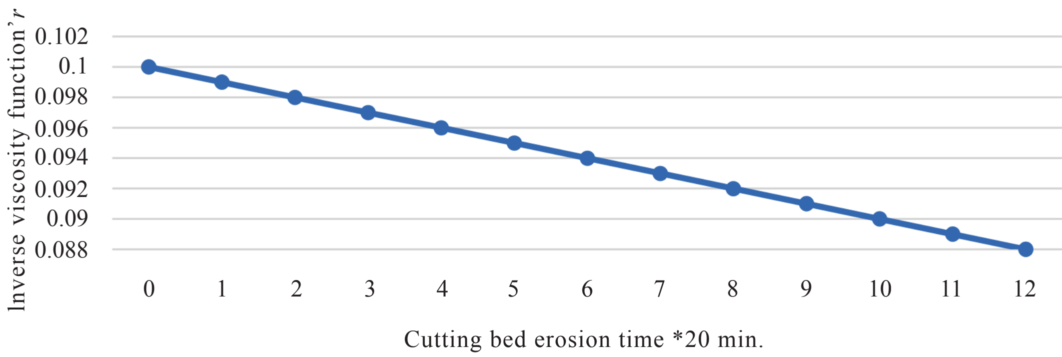

Figure 3
The Effect of Inverse Viscosity Function *γ* on Cutting Bed Erosion Time "*t*"

CONCLUSION

The results obtained from the two models have shown that when the viscosity for the base case drilling fluid was varied to form low and high viscosity fluids, each of these fluids were tested with Robinson model and the low viscosity drilling fluid gives an excellent hole cleaning for *CCI* = 1.03 with an optimum flow rate of 490 gpm, high viscosity drilling fluid gives a *CCI* values of 0.8 at flow rate of 490 gpm while the base case drilling fluid gives a *CCI* value of 0.9 at flow rate of 490 gpm. To achieve an excellent hole cleaning value (i.e *CCI* > or = 1), the flow rate must be increased to an optimum value of 570 gpm for the base case and and 630 gpm for high viscosity drilling fluid. These flow rate values for base case and high viscosity drilling fluid are not within the flow rate window for an 8 $^{1}/_{2}$ inch. open hole. With the same fluids tested with Noah model, it was noted that 199 minutes was used to erode a 5 inches cutting bed using low viscosity drilling fluid, while 563 minutes was used for the base case drilling fluid and 644 minutes for high viscosity drilling fluid. These results imply that at an optimum flow rate of 490 gpm with low viscosity drilling fluid, 199 minutes will be needed to erode a 5 inches cutting bed to 0.6 inches, using base case drilling fluid, 563 minutes will be needed to erode same cutting bed height while 664 minutes will be needed to erode same cutting bed height with high viscosity drilling fluid.

From these result, since low viscosity drilling fluid will take less than 30% of the time needed by the other drilling fluids, using the low viscosity drilling fluid also will take less than 30% of the cost that would have been spent by using the other fluids. With these, the fastest way to erode cutting bed can be achieved if a low viscosity drilling fluid is pumped at an optimum flow rate.

From this study, the following conclusion can be drawn:

(a) One of the best ways of reducing Non-Productive Time (NPT) related to hole cleaning in every drilling operation, is to pump low viscosity fluid at high flow rate prior to making a trip.

(b) Since low viscosity fluid is faster in cutting bed erosion, applying it prior to trip will save rig time and enhance the probability of successful completion of a well.

Suggested future works include carrying out similar work on water base drilling fluid.

REFERENCES

[1] Becker, T. E., Azar, J. J., & Okrajni, S. S. (1991). *Correlations of mud rheological properties with cuttings-transport performance in directional drilling* (pp.16-24). SPEDE March.

[2] Noah, A. Z. (2013). Optimizing drilling fluid properties and flow rates for effective hole cleaning at high-angle and horizontal wells. *Journal of Applied Sciences Research, 9*(1), 705-718.

[3] Peden, J. M., Ford, J. T., & Oyeneyin, M. B. (1990). *Comprehensive experimental investigation of drilled cuttings transport in inclined wells including the effects of rotation and eccentricity*. Paper SPE 20925 presented at Europec 1990, The Hague, Netherlands, October 22-24.

[4] Belavadi, M. N., & Chukwu, G. A. (1994). *Experimental study of the parameters affecting cuttings transport in a vertical wellbore annulus*. Paper SPE 27880 Presented at the Western Regional Meeting, Long Beach, March 23-25.

[5] Luo, Y., Bern, P. A., Chambers, B. D., & Kellingray, D. S. (1994). *Simple charts to determine hole cleaning requirements in deviated wells*. Paper IADC/SPE 27486 Presented at the SPE/IADC Drilling Conference, Dallas, February 15-16.

[6] Robinson, L. H (1993). Extracted from API recommended practice 13D. *Rheology and hydraulics of oil-well drilling fluids* (pp.41-42). 5th November 2009, SC 13/WG7.

