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Effective Hole Cleaning Beyond 25,000 Feet Challenges Industry Practices

Justin Parsons, James Strickland, and Matt Offenbacher, AES Drilling Fluids

Abstract

The Utica and Marcellus shale formations feature some of the longest horizontal land wells with lateral sections approaching 20,000 feet and total depths approaching 30,000 feet. With greater depths, hole cleaning concerns are magnified, but defying traditional hole cleaning practices has addressed these challenges to deliver clean wellbores for trouble-free trips and casing runs.

The hole cleaning methodology focuses on managing a turbulent flow regime, contrary to the preference of many experienced drilling fluid specialists. Conventional practices suggest elevated low-end rheology promoting laminar flow, but experience throughout numerous wells has demonstrated this practice actually compromises hole cleaning efficiency.

The pursuit of longer, more efficient wells requires an evaluation of traditional rules and expectations as demand for greater drilling performance under more challenging conditions grows. In line with proper fluid properties, complementary drilling practices including pipe rotation are essential.

The authors will compare conventional hole cleaning philosophy to the methodology employed, reviewing typical well profiles and how they have evolved over time. A review of example wells with fluid properties and drilling practices will further emphasize the success of this methodology that continues to deliver on ever longer horizontal wells.

Introduction

Historically, conventional hole cleaning practices employed general rules of thumb which supported the drilling conditions of the day. Hole cleaning concepts considered low end rheology at the primary consideration. The preferred tactic was to maintain the 6 rev/min reading to 1.5 times the hole diameter. These rules appeared effective for the circumstances – laterals of no more than 6,000 feet.

The desire to elevate pump rates resulted in a relaxation of elevated low end rheology. The higher pump rates appeared to aid in enhanced rate of penetration and the practice of lowering rheology in favor of higher pump rates became standard. It was believed this scenario was possible due to more benign drilling conditions. With economic drivers pushing longer horizontal wells, hole cleaning options were revisited.

Drilling Program Overview

The Marcellus and Utica shale formations are drilled throughout Pennsylvania, Ohio, and West Virginia. Extended lateral length is a key component in lowering overall drilling and production costs, and many operators continue to extend the length of horizontal wells. It is estimated that operators in the area will drill more than 40 wells with lateral lengths of 17,000 feet or longer in 2018.

Many wells are drilled from multiple-well pad sites to minimize local impact and efficiently access reservoirs. Marcellus and Utica wells and formations feature unique challenges addressed through standardized local best practices; however, much of the information provided applies to numerous wells outside the Northeast. For the purposes of discussion, this overview will review long Marcellus laterals.

Evolution of Practices

The availability of more powerful drilling rigs expanded drilling programs to feature wells with long horizontals at measured depths from 17,000 to 25,000+ feet. The dramatic increase in hole length, particularly horizontal length, led to a revisit of hole cleaning strategy.

A review of common practice, returned to rules-of-thumb, such as the 6 rev/min multiple mentioned. It was deemed necessary to return to these practices for more challenged wells.

This elevated rheology limited flow rates as the higher viscosity required more pressure to pump, resulting in a greater area of flow regime in laminar flow.

Results were mixed as difficulty on trips and running casing provided clear indications of poor hole cleaning. Computer simulation failed to offer guidance as contradicting results between the hole cleaning models limited confidence in their insight.

After further review, low shear rate viscosity was relaxed, focusing on maximum flow rate and related flow regime. Improved performance was noted immediately. Trips became smooth and there were no issues running casing to bottom. As lateral lengths became longer, consistency with these practices yielded consistent success. In the past several years, most rigs were upgraded 7500 psi pumps for sufficient pump rates across ever longer laterals. This new focus on turbulent flow has proven successful on over 400 wells to date.

Hole Cleaning Factors

Effective hole-cleaning must factor in a number of properties. Pipe movement, flow rate, and fluid rheology combine to convey cuttings from the bit to surface. Neglect of one of these components may result in poor results – excessive ECD with the risk of losses, excess torque, extra cleanout/reaming trips, difficulty running casing, and stuck pipe.

At extreme well lengths, added distance to convey cuttings reduces the margin of error. Proper discipline monitoring these factors aids to insure success, most of which extend beyond basic fluid properties into drilling practices.

This paper will focus on the horizontal sections and cite invert emulsion drilling fluid properties throughout; however, nearly all principles relate to a non-Newtonian drilling fluid.

Flow Rate, Flow Regime, and Drill Pipe

Flow rate provides energy to convey cuttings to surface through annular velocity while circulating. Sufficient flow rate will vary by hole size and pipe size as a direct correlation to the available flow area and annular velocity.

As many rigs upgrade to 7500 psi pumps, sufficient flow rate is available to drill further and maintain the proper flow regime in long horizontal wells. String design factoring optimal pipe diameter is a helpful yet often overlooked factor in hole cleaning efficiency.

Flow Regime

Flow regime is characterized by the Reynolds number, which is a ratio of inertial to viscous forces. Lower Reynolds numbers correlate with laminar flow and higher numbers correlate with turbulent flow, with a transitional flow state in between (Figure 1). The exact numbers are subject to some debate and depend upon the model and fluid in use[1]. API equations use power law calculations for flow regime[2].

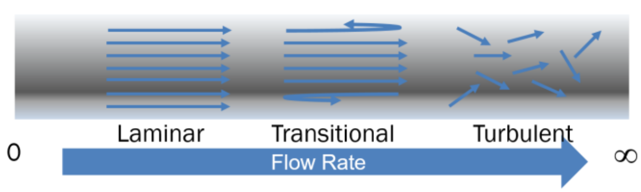

Figure 1: Increasing flow rate from laminar to transition to turbulent flow regime

Because flow regime is a function of annular velocity, the low-side of an extended lateral will have lower Reynolds number than the primary flow area. A typical response is to provide excess viscosity to insure suspension; however, the increased viscosity ultimately reduces the region of turbulence (Figure 2). Several authors discuss this issue as it relates to viscous sweeps[3,4].

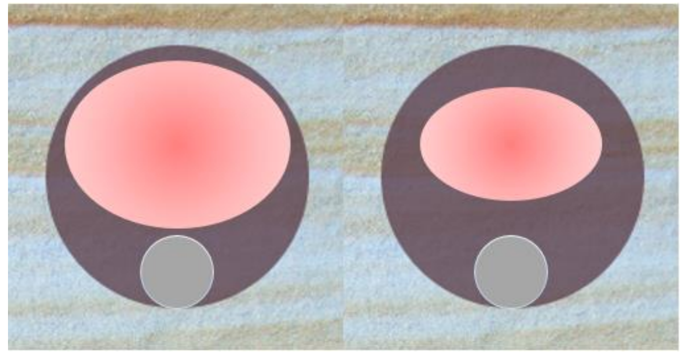
Figure 2: Lower viscosity (left) offers more a larger area of turbulence (red area) versus elevated viscosity shown at right.

Pipe Movement

Pipe movement aids in hole cleaning by constantly changing areas of insufficient flow and inhibiting the accumulation of material in a single location as it is physically agitated by the moving string. Excess pipe rotation results in higher ECD, but inadequate rates of pipe rotation result in poor hole cleaning[5].

With effective pipe rotation rates, the area of low flow constantly changes, limiting accumulation of cuttings. The mechanical rotation, in combination with reciprocation, returns accumulated cuttings to the primary flow path (Figure 3).

Figure 3: Pipe rotation alters high flow area in a horizontal section where pipe tends to settle at the bottom of the hole

Another complex mechanism is the introduction of turbulence from pipe movement throughout the wellbore, providing additional energy to that provided by effective flow rate. Previous work calculates this local velocity progressively increases with pipe rotation, but is nearly absent without pipe rotation[5].

Continuous circulation and pipe movement after drilling continues to remove accumulated cuttings. This is particularly important in longer wells with larger areas for cuttings to accumulate. Retracting the BHA as it drags across the bottom of the hole creates the potential to sweep cuttings into a large mass, risking packoff and other issues pulling out of the hole.

Cuttings Transport

Cuttings suspension models become increasingly complex as they attempt to account for all factors involved. Basic cuttings transport models compare the slip or falling velocity of a cutting to the upward velocity of fluid. Slip velocity is subject to a number of complex components – other cuttings that hinder rate of settling, cuttings density, flow regime, hole angle, and other factors[6].

Another key factor in cuttings transport is the contrast between mud density and cuttings density. Higher mud density provides buoyancy and lower the slip velocity. This effect also explains the appreciation for weighted sweeps to evaluate or aid in hole cleaning[3,4].

While many subscribe to a sweeps program, continual addition of weight materials can create challenges controlling mud density. The authors do not use sweeps, relying on an optimal hole cleaning environment through best practices.

Rheological Requirements, Measurements, and their Limitations

A detailed review of typical measurement methods reveals significant error and inconsistency. Trending may explain the correlation between some level of insight and success; however, almost every field measurement features a reasonably high degree of error.

Rheological Requirements

Mixing energy is the primary conveyor of cuttings to surface, but a minimum viscosity is required to aid in suspension and suspend weight material. Sag is one reason to maintain low shear viscosity at a minimum value[10]; however, sag events are typically dynamic events that include multiple factors beyond rheology[8].

As discussed previously, excess viscosity reduces the area in the annulus where turbulent flow is available to convey cuttings. Balancing the appropriate viscosity for suspension without excess aids to insure effective hole cleaning while mitigating sag risk.

Limitations of the Marsh Funnel

In many areas, wells are drilled from pads to gain broad access to reservoir targets. When multiple wells are drilled from the same location, many drilling and fluid properties remain identical throughout a campaign. This may facilitate some reliance on less precise instruments for trending purposes, but the exact values fail to provide information for more in-depth analysis.

The Marsh funnel viscosity serves as an indicator of trends, but overall this instrument offers little to no value to model hole cleaning properties. Generally speaking, the Marsh funnel is an unreliable instrument. Its shape and the change of hydrostatic head in the funnel itself during measurement (Figure 4) means that shear is constantly changing throughout the time of measurement.

Figure 4: The Marsh funnel has a constantly changing rate of hydrostatic pressures and shear as fluid passes through, making it a poor instrument for precision measurements

There is no standard temperature for measurement using a Marsh funnel. Numbers vary by flowline temperature, weather, and sampling location. In Figure 4, hundreds of readings show the incredible variation of readings by mud weight throughout a wide range of locations.

It's clear that funnel viscosity fails to follow any trend for use in broad analysis, but the simplicity of the test and broad availability of the equipment allows minimally trained personnel to easily track and report trends.

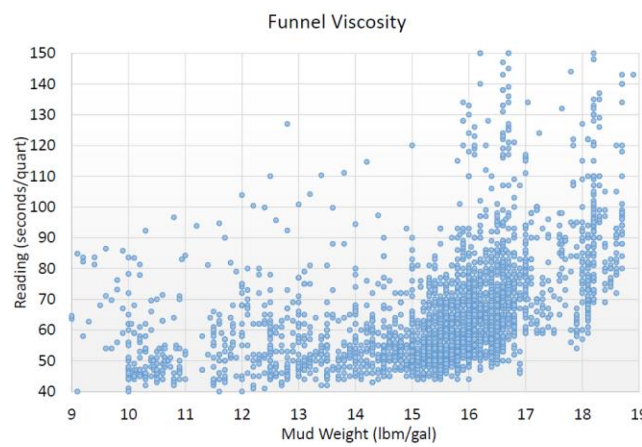

Figure 5: Funnel viscosity versus mud weight

API Recommended Practices 13D[8] recognizes the trending potential of a Marsh funnel, but recommends subsequent testing with a coaxial viscometer for proper analysis.

Error in Low Shear Dial Readings

Coaxial viscometers offer more consistent measurements with standard recommendations for measurement at a constant temperature. There are a number of models available, with most field instruments featuring a sight glass to read the appropriate value across six speeds/shear rates (Figure 6). Electronic readout models are available; however, their use in the field is not as widespread.

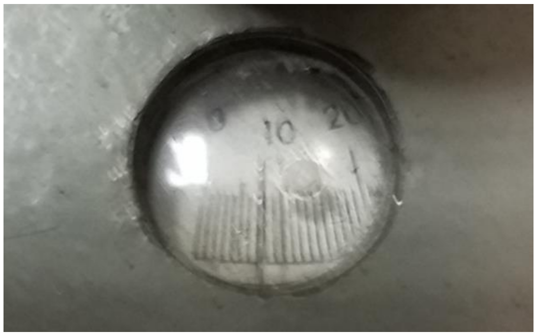

Figure 6: Sight glass for readings with a typical six-speed viscometer

600 rev/min and 300 rev/min readings provide yield point, plastic viscosity. 6 and 3 rev/min readings are considered low shear relative to the other standard readings. Many rules of thumb cite 6 and 3 rev/min readings to address hole cleaning; however, the instrumentation and subjective reading of the 3 rev/min reading limits the reliability of these methods.

A comprehensive review of drilling fluid reports shows that drilling fluids follow a Hershel-Bulkley model – with the exception of the 3 rev/min reading. This reading remains within the error of the 6 rev/min reading, and in many cases, should be reported as the same number as the 6 rev/min reading.

Without decimal readings between degrees of deflection, the drilling fluids specialist must make a determination as to how to report the low shear reading. In almost every case, this input is 1 degree less than the 6 rev/min reading due to discomfort reporting identical numbers at two different shear rates.

The 6 rev/min is a more reliable approximation, but the inherent error of reading even a well calibrated instrument limits the precision of the recorded value. As a low shear reading, it proves sufficient for trending.

Yield Stress Approximation

The accepted Herschel-Bulkley model provides an accurate and reliable means to calculate viscosity across the full spectrum of relevant shear rates (as compared to Bingham-Plastic and Power Law). The model uses the yield stress, or τ_y, where the model intersects the y-axis at zero shear.

Measuring yield stress requires special instrumentation that is not widely available. To simplify this issue, the yield stress is substituted for the low-shear yield point, which is calculated by doubling the questionable 3 rev/min reading and subtracting the 6 rev/min reading[2]. Spreadsheet tools help to calculate a yield stress, but they require a more involved process to extrapolate values versus simple math equations[9].

Typical Practices

Conductor is driven and two sections are air drilled to isolate the water table and coal sections with casing set and cemented. Cement is drilled out using an 8 ¾" bit, continuing to air drill into the kickoff point. The well is then displaced to invert emulsion drilling fluid, reaching true vertical depths ranging from 7,000 to 10,000 feet before holding horizontal angle.

The remainder of the curve and lateral is drilled with a rotary steerable tool using an 8 ½" bit. Typical mud weight ranges between 12.5 and 13.5 lbm/gal. For most operators the lateral section is cased with 5 ½" casing.

Rheology is maintained with a 6 rev/min reading of 6-7 degrees. Yield point ranges between 10 and 14 lb/100 ft^2 with plastic viscosity held below 30 cP. Gels are monitored to insure that progression is not excessive.

Target flow rates range from 500-600 gal/min using 5" drill pipe to surface. This provides annular velocities between ~260 and 310 feet per minute. Pipe rotation ranges between 120 and 150 rev/min to insure orbital movement in the wellbore.

Rates of penetration target reaching technical limits, balancing the conveyance of cuttings to surface with rate of cuttings introduction to the system. Typical rates of penetration range from 150 to 300 feet per hour. Experience monitoring at the shakers provides an indicator of hole-cleaning, along with a PWD tool to identify excess pressures indicating cuttings loading.

At TD, a circulation continues, carefully observing returns at the shakers while rotating and reciprocating pipe. A total of 5-6 bottoms' up are considered the minimum time for cleanup of residual cuttings. This process continues if the cuttings continue to appear at the shakers.

With the shakers clear of cuttings after the minimum number of circulations, the BHA is pulled out of the hole for the casing run.

Conclusions

Extended laterals continue to gain popularity as efficient delivery makes them economical. Hole cleaning is a critical factor in drilling efficiency, but hole cleaning is frequently associated only with rheology.

- Historical focus on low shear rate viscosity is insufficient
- Hole cleaning is a function of pipe movement, flow rate/regime, and viscosity
- Hole cleaning factors cannot be taken in isolation
- Field instrumentation relied upon for measurements to indicate hole cleaning efficiency have limitations in accuracy and reliability. Consider focusing on the 6 rev/min reading for low shear readings
- Standard drilling practices for the operator include focus on flow rate and sufficient pipe rotation along with proper rheology
- Experienced personnel monitor returns at the shakers to observe cuttings returning to surface
- Cleanup circulations at TD aid to insure a clean hole for tripping and casing running
- Discipline maintaining key parameters is essential for consistent results

Acknowledgments

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Nomenclature

ECD = *Equivalent circulating density*
TD = *Total Depth*
PWD = *Pressure While Drilling*
BHA = *Bottomhole assembly*

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