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Eliminating Pressure Spikes after Connections and Trips to Improve ECD Control and Minimize Downhole Losses

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Abstract

When initiating circulation after downtime for connections or trips, many operators bring the pumps up slowly to prevent significant pressure spikes that can cause lost circulation. In some cases, the drillstring is staged into the hole with intermittent pumping to minimize the impact on equivalent circulating density (ECD) after a static period.

On a deepwater well in Mississippi Canyon, an operator encountered this issue while drilling the 22-in. hole with a conventional clay-based synthetic-based mud (SBM). After connections, data from the pressure-while-drilling (PWD) tool showed pressure spikes 0.5-1.2 ppg higher than the drilling ECD. This "mini-fracing" of the formation led to lost returns and ultimately wellbore collapse.

When the operator planned a deepwater sidetrack in the Mississippi Canyon area later in the drilling program, a clay-free SBM was selected. The well program called for milling a window in the existing 9 5/8-in. casing and drilling a 9 7/8-in. hole with a maximum deviation of 40º.

The drillstring included 5-in. drill pipe with 6 3/4-in. tool joints. Despite the tight tolerances, the operator was able to eliminate pressure spikes, even when bringing the mud pumps to 3,000 psi in less than five minutes after connections. The ECDs on the 9 7/8-in. open hole averaged 0.5 ppg, significantly lower than ECDs experienced on the offset well using a clay-based SBM.

There were no downhole mud losses observed while tripping, running casing or cementing.

This paper compares fluid hydraulics and drilling performance between the two wells based on PWD data and fluid properties.

Introduction

The gel strength of a drilling fluid is the shear stress measured at a low shear rate after a fluid has been static for a period of time, typically measured at 10 seconds, 10 minutes and 30 minutes. More simply, it represents the fluid's ability to suspend solids while in a static state. Resuming circulation after a static interval disrupts the gel strength, and the amount of pressure required to do this depends on the fluid type and rheological properties.

When initiating circulation after downtime for connections or trips, many operators bring the pumps up slowly to prevent significant pressure spikes that can cause lost circulation. These spikes can occur after connections while ramping the mud pumps up to full drilling flow rate and breaking the gels formed by the drilling fluid.

Typically, gel strengths generated with a clay-based fluid do not exhibit a rapid gel-to-flow transition after a static period, so that extra pressure must be applied to break the gels. This results in the formation being exposed to higher ECDs in the form of pressure spikes. These spikes can be as low as 0.1 ppg, or exceed 1.0 ppg. Generally the spike is just that: a sudden ECD increase of short duration observed when breaking the gel strength. When the fluid begins moving, the normal ECD is restored.

The severity of pressure spikes observed after connections depend on several variables, including but not limited to the following:

- Time required for connections
- Drilling fluid properties
- Hole geometry
- Well conditions
- Drilling practices

Due to the nature of gel strengths, time and fluid properties may be the biggest contributors to pressure spike intensity. The duration of the static period can have an effect on the gel strength built. As shown in **Figure 1**, fluids that exhibit sharply progressive gel structures will continue to build gel strength over time. In fluids with a flat gel structure, the gel strength reaches a peak after a specific period of time and does not increase further.

Progressive gels can require significantly more breaking pressure before the mud resumes normal flow, adding to the ECD seen by the wellbore. Clay-based SBMs usually exhibit progressive gels due to the gel structure of the organophilic clay. By contrast, gels formed by a clay-free SBM build quickly then reach a plateau (typically after 20-30 minutes). The gel strength is sufficient to suspend solids and weight material, but it is also easily disrupted when pumping is initiated.

While the gel strength developments illustrated in Figure 1 seem similar up to a 30-minute duration, the real story begins after 30 minutes, when the progressive gel continues to build, while the flat gel stops and remains steady at the maximum value achieved.

Causes and Mitigations for Pressure Spikes

As noted above, a number of factors can affect gel strength and the pressure needed to resume circulation. Hole and drillstring geometries that create tight tolerances can increase the severity of pressure spikes. Initiating fluid movement in limited annular space (e.g., around the BHA and tool joints in casing) can lead to higher than normal pressures.

Temperature can also affect gel strength. For example, in deepwater the temperature at the seafloor is +/- 40°F. Some fluids thicken significantly at this low temperature and require increased pump pressure to break gels.

Drilling practices can have an impact on the ECD experienced by the exposed formation. Bringing the pumps to full drilling flow rate rapidly rather than staging the pumps up gradually can increase ECD significantly. This effect is especially pronounced with a clay-based SBM. Therefore, drilling with a clay-based fluid may require extra care while bringing the pumps all the way to full drilling rate, unless the formation has a sufficient pore pressure / fracture gradient (PP/FG) margin to withstand additional stress from a pressure spike. To minimize this risk of spikes and excessive ECDs, operators typically ramp up the mud pumps in a controlled manner. This helps them avoid surging the hole or damaging rig equipment.

In some cases, the drillstring is staged into the hole with intermittent stops for pumping to minimize impacts on ECD. In this tripping method, the pipe is run in the hole to a predetermined depth (usually 2000-ft to 5000-ft increments) and the mud is circulated and conditioned. After circulation has been established, the pipe is tripped deeper and circulation broken again.

This method is used when the drilling fluid exhibits sharply progressive gels and circulation cannot be initiated without generating a pressure spike that would induce catastrophic losses or exceed the standpipe pressure rating. As a result, trip time is extended when the mud exhibits progressive gels, since it takes longer to achieve full circulation rate at each stopping point. Further, the mud may require more frequent stops over shorter intervals to break circulation. The additional time required on trips is dependent on hole geometry, mud properties and operator preference.

Another variable is cuttings loading. After periods of fast drilling, when the cuttings load in the annulus is high, a pressure spike can occur, especially in a restricted annulus. And when the operator must decrease the rate of penetration in an attempt to reduce ECD, the entire operation slows down.

The rheological properties of the fluid are also important. When these properties exceed specified values, they contribute to pressure spike severity.

Any combination of these factors is likely to worsen the spike, even after a short static period.

Selecting a Fluid for Deepwater Applications

The type of drilling fluid selected can make a significant difference in wellbore stability and drilling efficiency related to static-to-flow transitions. As noted above, rheological properties, particularly gel strength, is one of the most important attributes to evaluate. To preserve efficiency and protect the wellbore, a rapid-building flat gel that is easily broken with minimal pressure is optimal.

While it is true that wells with a sufficient fracture gradient to withstand ECD spikes have been drilled successfully with clay-based systems despite their characteristic progressive gels, this is rarely the case in Gulf of Mexico deepwater drilling.

Since the industry began drilling in water depths of 3,000 ft or more, the problem of maintaining consistent and desirable mud properties over a wide temperature range has been the catalyst for several fluid designs.[1,2] The shear-thinning ability of the fluid – i.e., its ability to transition from gel to fluid when subjected to circulating pressure and pipe rotation – is a primary criterion for managing ECD and staying within the narrow PP/FG margins that are commonly seen on deepwater wells.

Two-Well Comparison: Annular Area and Other Factors

The difference can be clearly compared between the pressure spike intensity observed with a clay-based system and that observed with a clay-free SBM. The same operator drilled two development wells in Mississippi Canyon, using a clay-based system on the first well (Well 1) and a clay-free SBM on the second well (Well 2).

While at first glance, conditions on these wells seem completely different, in actuality one would expect Well 1 to have fewer and less severe pressure spike issues. That was not the case.

Well 1 was located in 3,900 ft of water. The operator first encountered problems while drilling a 22” hole using 6-5/8” drill pipe with 8-1/2” OD tooljoints. This combination calculates to an annular area of 323 square inches.

Well 2 was drilled in 3,000 ft of water. The interval of interest on this well was the 8-1/2” x 9-7/8” sidetrack out of 9-5/8” casing (ID 8.535”). The drill pipe on Well 2 was 5”, with 6-3/4” tool joints. This geometry yields a scant 21-square inch annular area **(Figure 2)**.

Clearly the significant annular restriction on Well 2 would affect fluid hydraulics in terms of flow and pressure impacts. The mudline temperature for both wells was +/- 40°F.

Well 1: Clay-Based SBM. The operator commenced drilling Well 1, setting 22” casing after drilling riserless to 5,900 ft TVD. After running 3,900 ft of riser, the well was displaced to a clay-base SBM and the next interval drilled was an 18” x 22” hole for setting 18” casing. The BHA consisted of 9-1/2” tools and the drillstring was 6-5/8” drill pipe.

Shortly after opening the reamer, the rigsite team began observing pressure spikes while initiating circulation after connections. The first spike measured 0.3 ppg equivalent, and spikes on subsequent connections escalated to 0.5 ppg, then

0.7 ppg. The well experienced lost circulation and LCM was added to combat the losses. They continued drilling ahead, while pressure spikes from pack offs and after connections reached as high as 1.15 ppg over drilling ECDs.

When the pressure exerted on the wellbore exceeds the fracture gradient of the formation, the formation is fractured, or frac'd. This process is typically used in production operations to open the formation and allow the produced fluid or gas easier entry into the wellbore. In the case of drilling, the same frac effect holds true, although the flow is reversed. As the fractures are opened, the drilling fluid is forced back into the formation. The pressure spikes recorded after connections are essentially mini fracs that open fractures in the formation and force drilling fluid into them. While this frac is not sustained as it would be for an enhanced production application, these "punches" to the formation can weaken it and lead to other issues not easily remedied.

In Well 1, this "mini-fracing" of the formation led to lost returns and ultimately wellbore collapse.

Another risk related to severe pressure spikes is hydraulic sloughing of the formation. As the formation is fractured, not only can it result in lost circulation, but as mud is forced into the fractures it can pry the weakened formation into the wellbore, similar to the heavings of a pressured shale. This can increase an already large load of cuttings in the annulus and cause severe pack offs that further damage (or weaken) the formation.

Lost circulation, wellbore instability, pack offs, stuck pipe, and excessive ECDs can all result. Pack offs and increased ECDS can further aggravate the problem, and ultimately the wellbore can be lost, requiring significant downtime to set cement plugs, and sidetrack.

Most of these issues were encountered while drilling the 22" interval on Well 1. The pressure spikes eventually led to severe lost circulation and the ensuing battle to restore returns. The effort to regain wellbore stability was not successful. The fractures led ultimately to wellbore collapse, despite costly attempts at remediation. The non-productive time (NPT) included mixing and pumping LCM, followed by treatment with more intensive LCM pills, and the wait time required to see the outcome. On Well 1, after the wellbore collapsed, days were spent trying to get back into the original hole, tripping for a cement stinger, setting and waiting on cement, and then redrilling the interval.

Well 2: Clay-Free SBM. Well 2 was a Mississippi Canyon deepwater sidetrack drilled with clay-free SBM. This sidetrack commenced with a milling operation out of 9-5/8" (8.535" ID) casing. The water depth was 3,000 ft, and the well plan called for drilling an 8-1/2" x 9-7/8" hole to a maximum deviation of 40°. The operator used the rig-supplied 5" drillstring with 6-3/4" tool joint diameter. The BHA consisted of 6-3/4" tools.

As noted above, the operator chose a clay-free SBM to drill the sidetrack. Despite the tight tolerances between the 6-3/4" tool joints and 8.535" ID of the 9-5/8" casing, no pressure spikes were detected after connections (**Figure 3**).

The pumps were brought online in a similar manner to the first well: from 0 to @ 3,000 psi in less than five minutes, and generally less than two minutes. The proprietary chemistry of the clay-free fluid allowed for rapid gel-to-flow transition so that the fluid resumed flow without adding pressure to break the gels, or subjecting the formation to pressure spikes.

The ECDs on the 9 7/8-in. open hole averaged 0.5 ppg, significantly lower than ECDs experienced on the offset well using a clay-based SBM. Further, there were zero downhole mud losses observed while tripping, running casing and cementing.

The proprietary chemistry of the clay-free SBM contributed to these results on Well 2.

To truly provide the type of performance described above, an oil- or synthetic-based drilling fluid should exhibit the five characteristics shown below. All five attributes should be present as it is the combination of traits that leads to the unique behavior and premium performance of these clay-free fluids:

- High Viscosity Index: little change in dynamic viscosity with changing temperature
- Shear-thinning: viscosity decreases with an increase in shear rate
- Thixotropic: shows decreasing viscosity over time at a constant shear rate
- Flat gel strengths: increasing yield stress over time, reaching a limit after 20-30 minutes
- Fragile gel strengths: easily disrupted gel strengths broken by shear, allowing the fluid to return to its original rheological properties, then quickly revert to a gelled state when applied shear ceases

Of these attributes, the one most responsible for pressure spikes, or the lack there of in this case, is the fragile gel strength.

Figure 4 shows the difference in breaking gel strengths built by clay-based and clay-free SBMs. While the fluids have little similarity, conventional thinking would lead one to believe the heavier clay-free fluid would have higher gels to prevent sag, and therefore it would be harder to initiate flow. That was not the case.

Each data point on the graph represents 0.5 seconds, and the graphs were cut off when the slope of the line was greater than -1 for two consecutive readings, which was assumed to be the initiation of flow. While the peaks of the two fluids are relatively close, 22 for the clay-free SBM and 26 for the clay-based SBM, the differentiator is the time after the peak.

The clay-free SBM reaches it peak more rapidly and flow is initiated almost 30 seconds faster. Of particular importance is the time immediately following the peak. The clay-based SBM gels take considerably longer to break. The clay-free fluid gels are easily disrupted, and it is this characteristic that allows the clay-free SBM to eliminate pressure spikes after connections.

Conventional wisdom could lead to the opinion that fragile gels may promote a tendency toward barite sag in low shear environments such as running casing or tripping slowly. The chart below shows this is not the case.

Using a viscometer capable of very low shear readings, clay-based and clay-free SBMs of similar weights were compared. While the clay-free fluid appears to be thinner in the 100 rpm down to 3 rpm range, it exhibits a relatively flat viscosity profile at ultra low shear rates **(Figure 5)**. This viscosity profile prevents sag.

Conclusions

There are many factors that can lead to pressure spikes after connections. These include hole geometry, ROP, drilling practices, the speed in which the mud pumps are ramped up to full drilling rate, and of course, the drilling fluid itself. While most of these can be mitigated in one way or another, the easiest solution is to use a clay free fluid that has a robust, rapid building, but fragile gel strength.

These factors can be eliminated or mitigated by drilling with clay-free fluid exhibiting the following characteristics:

Acknowledgments

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References

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2. Burrow, K., Carbajal, D., Kirsner, J. and B. Owen. 2004. Benchmark Performance: Zero Barite Sag and Significantly Reduced Downhole Losses with the Industry's First Clay-Free Synthetic-Based Fluid. SPE 87138, IADC/SPE Drilling Conference, 2-4 March, Dallas, Texas

Figures

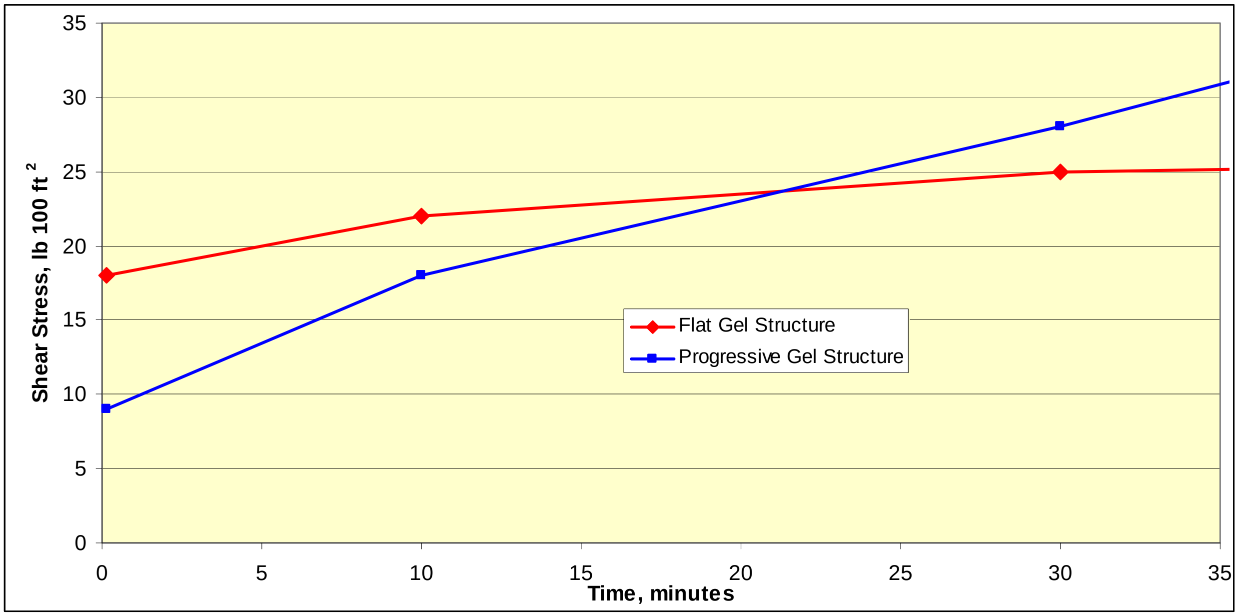

Figure 1 Gel strength development over time: flat gel vs. progressive gel.

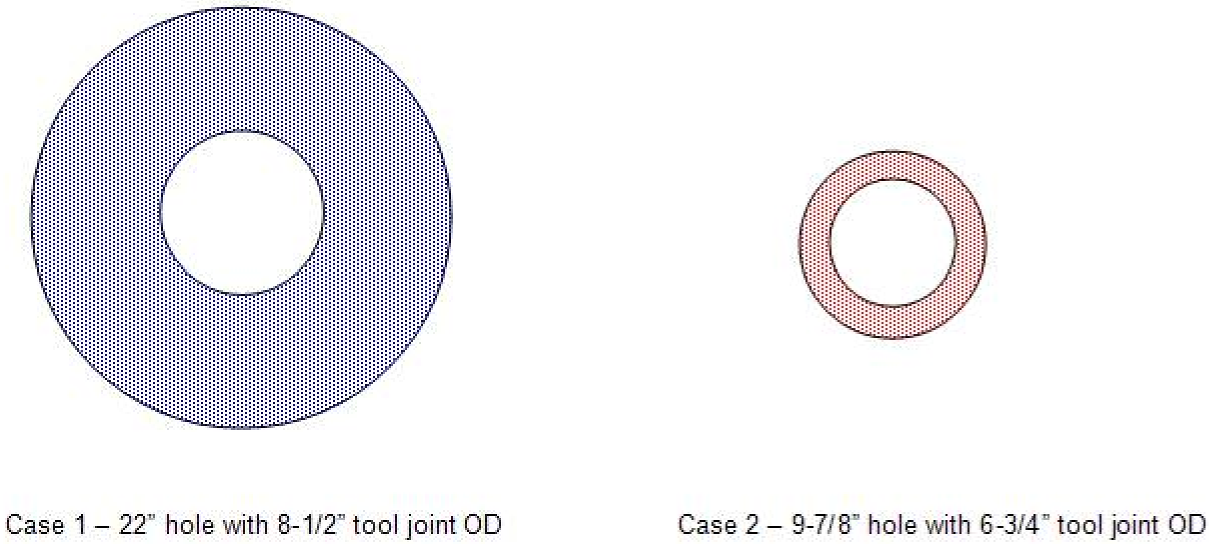

Figure 2 Comparison of annular area between Well 1 (clay-based fluid) and Well 2 (clay-free fluid).

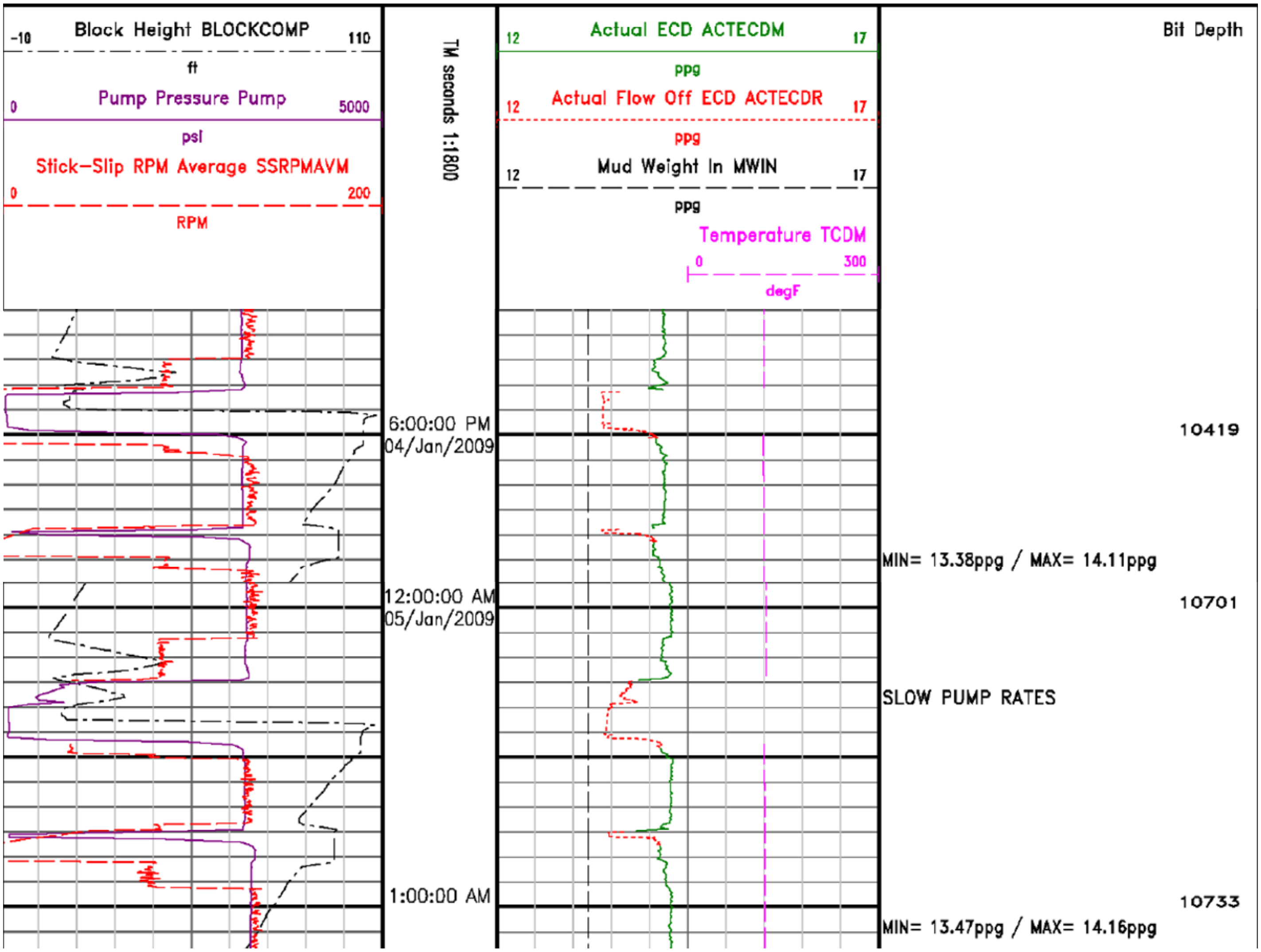

Figure 3 PWD log obtained from Well 2 (clay-free SBM) shows minimal pressure increases after static periods.

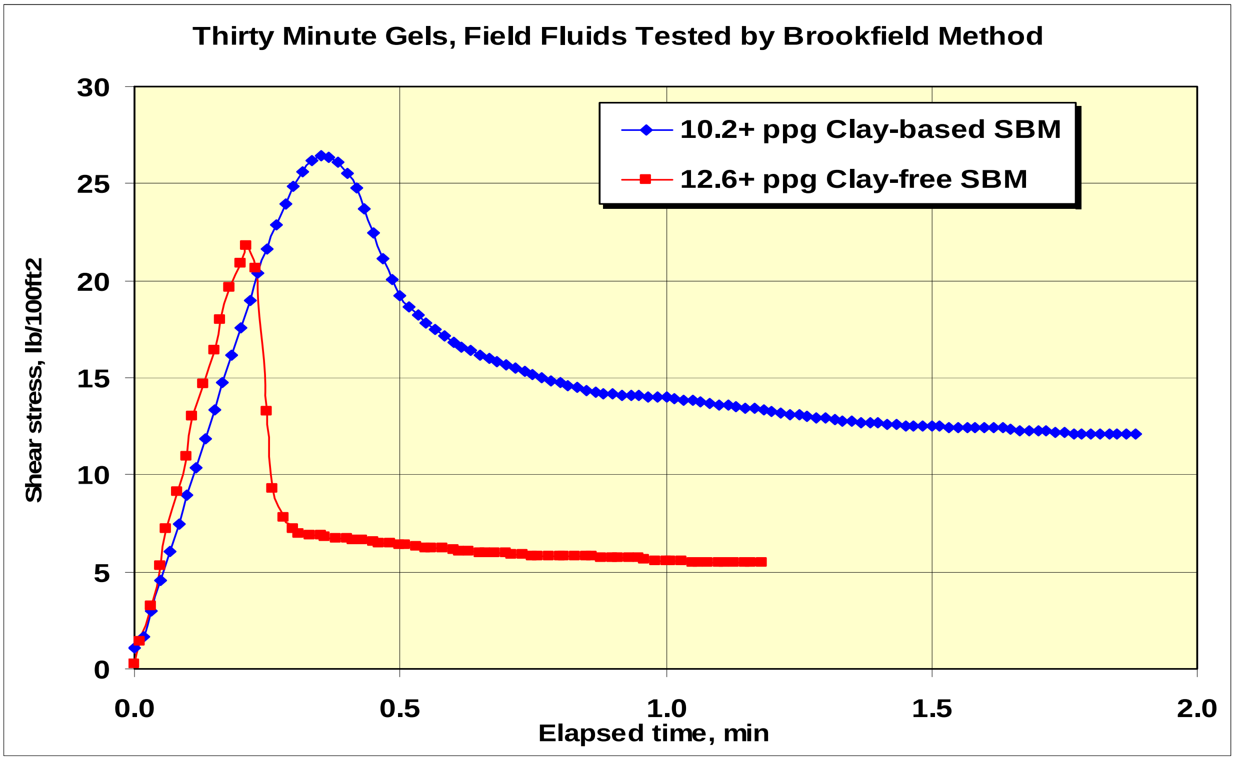

Figure 4 Comparison of shear stress required to break gel strengths built by clay-based and clay-free SBMs.

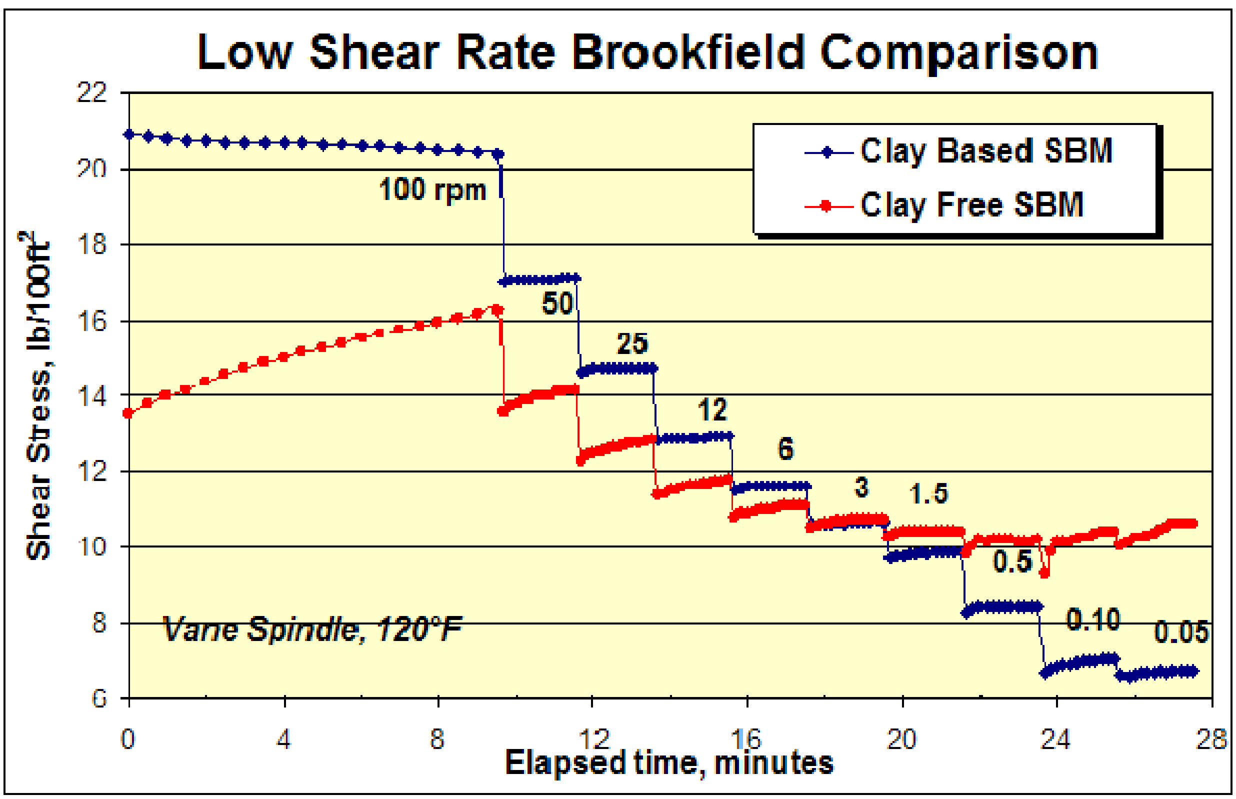

Figure 5 Comparison of ultra low shear readings for clay-based and clay-free SBMs of similar weights.