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The Importance of Novel Manufacturing Technology in Oil-Based Mud Mixing

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Abstract

Fluid service suppliers are under increasing pressure to deliver high quality oil based muds (OBMs) quickly, efficiently, and cost effectively. Combined with the increasingly more sophisticated and sensitive drilling fluid chemistries being used, conventional low shear fluid mixing equipment is often incapable of meeting industry needs.

A modernized mixing system design equipped with mechanical components meant to support the need for stabilized emulsions, minimized mix times, and full solubilization of expensive additives, can support service providers through improved mixing efficiencies. This modernized mixing system incorporates an LSL ("Liquid Shearing Liquid") concept as described in this paper. Through optimized design and LSL, service providers can deliver highly engineered technical fluid systems with greatly improved cost effectiveness.

This paper focuses on the mechanical design differences between a system designed to incorporate LSL technology and conventional mixing equipment. Two different OBM systems were tested in both the LSL and conventional systems, and the results were compared. Both comparisons, the mechanical and fluid tests, represent attempts to show the value in modernizing drilling fluid mixers.

Laboratory tests presented in this study represent traditional methods fluid service providers use to evaluate the quality of their fluid systems. The results show that mud properties, when blended with LSL technology, are improved compared to conventional low shear systems.

Introduction

Through the years, the oil industry has relied on continuous developments in oilfield chemistry and process technologies to produce high quality drilling fluids which allow for the safe and efficient extraction of oil and natural gas. The most complex fluids are typically oil-based muds which require additives that are difficult to disperse, emulsify, and activate in solution. Traditionally, fluid systems are prepared using conventional fluid mixers that utilize low horsepower centrifugal pumps and mixers. These mixing systems take long periods of time and require the high shear produced at the drill bit to fully activate the additives. Additional time and unintended additive usage inadvertently increases the costs of drilling fluid services. A system that would introduce sufficient shear and dispersion in a short period of time would provide cost and performance advantages to fluid service providers utilizing such a system.

One novel high shear mixing technology is known as LSL, or "Liquid Shearing Liquid" technology. The subject of this study is to determine the importance of implementing LSL technology in modern day fluid service operations. This technology, at the time of publication, has not been compared to conventional low shear mixing systems on an actual pilot batch scale, and thus became the subject of the current study.

To perform the comparison, a portable mixer containing a single LSL mixer and a single low shear propeller-type mixer in side-by-side 60 gallon tanks was used. A 10 lb/gal and 14 lb/gal OBM were tested in each tank, with numerous mud quality checks performed at intervals during batch production.

Overview of Existing Turbine Technology and High Shear Systems Traditionally Available

Traditional mixing techniques and equipment such as mud guns, impellers, and low horsepower mechanical mixers are not as capable or efficient at achieving the desired properties of drilling fluids due to the lack of high shear capabilities. This can result in increased mix time, unstable emulsions, poor low end rheology, and separated fluid systems. Designs that produce sufficient shear, such as a rotor stator arrangement, can struggle with high viscosity fluids and high solids loading due to the close tolerances inherent in the rotor-stator design. Saw-tooth designed shear mixers, commonly called Cowles blades, can be effective but are not efficient in large volume tanks and can take long periods of time to achieve the desired properties. Other designs such as hydrocavitation equipment are expensive and can be inefficient. Systems that produce sufficiently high shear can also damage the long polymer chains and degrade the chemical structure of some drilling fluids.

Proposed High Shear Turbine System

A shearing and mixing system is proposed that utilizes "Liquid Shearing Liquid" (LSL) technology. This system also incorporates fluid vortex depth control, internal heat generation, and traditional shearing techniques such as jet nozzles and pump impellers to produce high quality, stable OBMs. Figure 1a below shows such a horizontal system and fig. 1b shows a vertical system.

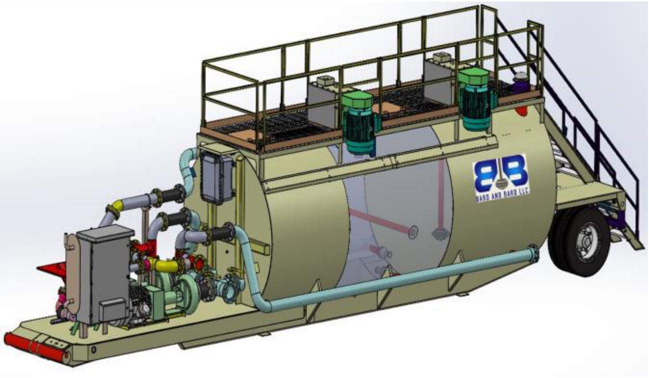


Figure 1a. Horizontal high shear mixing system.

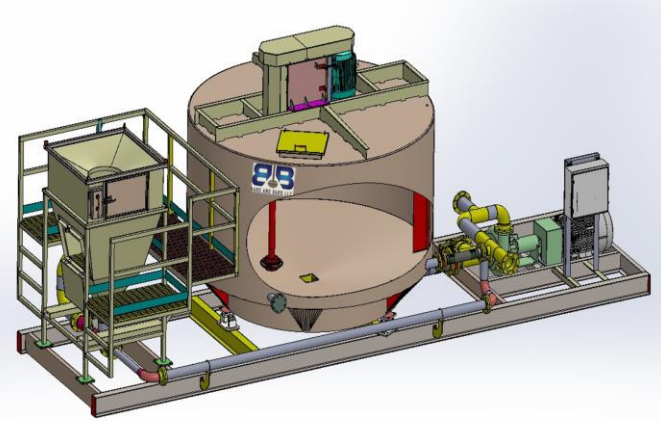


Figure 1b. Vertical high shear mixing system.

The key components of this system are discussed below:

Turbine Shear Mixer Head

The turbine consists of three parts: A) top casting, B) bottom casting, and C) dividing dispersion plate as shown in fig. 2. The turbine has eight fluid paths on the top casting and eight fluid paths on the bottom casting. Each casting has four intake ports that take in two-thirds of the material being mixed and four intake ports that take in one-third of the material being mixed.

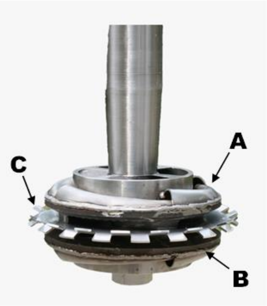


Figure 2
Turbine shear mixer

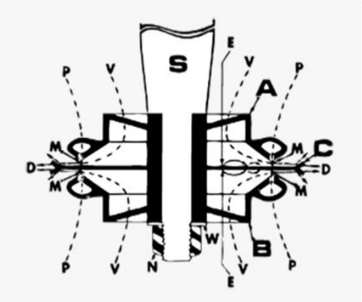


Figure 3
Turbine shear diagram

The principle of operation can be described as follows (refer to fig. 3):

E/E: Material from above the turbine and below the turbine is drawn in and expelled out equally against the dispersion plate. **V:** Indicates two-thirds of the fluid and its passage through the turbine at point M. At point M it is a large volume, high velocity, low pressure stream. Velocity is due to the centrifugal force created by the high speed of the turbine. Low pressure is gained by the venturi shape of the interior passageway of the turbine. **P:** Indicates one-third of the fluid and its passage through the turbine at point M. At point M, this one-third of the fluid is a low volume, high velocity, high pressure jet stream. The desired high pressure is obtained by the higher speed of the outside area of the (wheel) turbine. **M:** Indicates the Pressure-Volume Varied Mixing Point. This is where the vertical high-pressure fluid (*P*) tangentially intersects the low-pressure stream (*V*) resulting in instant wetting of powders and a “liquid shearing liquid” zone. **D:** Dispersion pattern of fluid discharging horizontally into the mixing tank.

Because the shear is generated by the intersection of the liquid streams, long chain polymers and chemical structures can be activated without damaging them.

Vortex Control and Fluid Flow

Due to the high rotational speeds of the turbine shear heads, vortexes are formed in the fluid and risk exposing the turbine shear head. This results in air entrainment, reduced powder wetting, and less efficient shearing of the fluid. Current mixing tanks are typically rectangular in their geometry and have internal gun lines running along the length of the tank. This design will have flow dead zones due to the right angles of the tank interior walls and stagnant areas from flow eddies induced by the gun lines impeding the fluid flow. These dead areas allow solids to settle and disrupt the internal fluid flow to the turbine shear head and results in increased mixing time and lower quality fluids.

The improved mixing system addresses these concerns in the following ways: Vortex depths and stagnant areas are controlled by turning the fluid into and on top of the vortex created by the turbine shear mixer head and by designing an obstruction free interior for undisturbed mixing. In vertical tanks, this is accomplished by strategically placed baffles that direct the fluid to the vortex. Horizontal tanks accomplish this by 1) moving the gunline pipe to the outside of the tank to remove obstructions to flow and 2) alternating the gun line nozzle location and alignment of the nozzles to effectively sweep the bottom of the tank and push fluid up the side walls and onto the vortex formed by the turbine shear mixer head. In addition, tanks are round, not rectangular, which provides smooth surfaces for fluids to flow over and reduces dead zones and eddies.

Eductors, or “jet nozzles”, are also used on the gun line discharges to pull in the surrounding fluid and expose it to additional shear. Figure 4 shows a typical arrangement of jet nozzles and turbine heads in a horizontal tank.

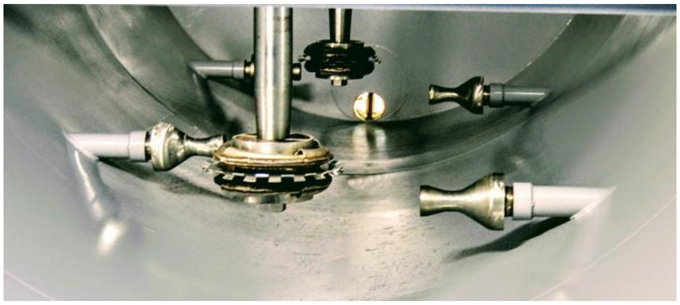


Figure 4. Eductor spray nozzles in a horizontal mix tank next to a turbine shear mix head.

Horsepower and Internal Heat Generation

The LSL system uses more horsepower than traditional mixing, pumping, and educting systems, but less than some other technologies like hydrocavitation and some rotor-stator pumping systems. This moderate horsepower system distributes the workload between the circulation pump, jet nozzles, and the turbine shear mixing head. The shear head requires additional horsepower over traditional mixers due to its design. The high rotational speed of the turbine head coupled with the sixteen (16) fluid inlet ports (8 top and 8 bottom), all of which have decreasing cross-sectional areas, will accelerate the liquid streams to the pressure-volume varied mix point in the turbine shear mix head. Moderate horsepower requirements of 40-75 horsepower motors are used to ram load the fluid inlet ports and build the needed pressure to drive the fluid through the turbine, to the mix point, and tangentially out the mix head. An additional 75-100 horsepower (150-200 in dual pump systems) are required in the circulation pump(s) to push fluid through the gun lines, out the jet nozzles, and into the tank.

As liquid passes through a centrifugal pump, most of the energy is transferred as a pressure-head increase, commonly known as the “pump efficiency” on a pump curve. However, some energy is dissipated into the fluid causing a temperature increase. The design of the turbine shear mixing head is analogous. The energy not used to force fluid through the ports is dissipated as heat into the fluid. The multiple internal fluid channels provide a relatively large surface area to efficiently disperse the energy as heat into the fluid. In real-world applications, the LSL system can raise the temperature of a 75 BBL unit by 1°F per minute depending on fluid type and ambient conditions.

Method Used in the Study

To determine the improvement in mud properties using high shear LSL mixers, as well as the reduced time required to prepare muds compared with conventional low shear mixers, a small commercial pilot mixer was obtained that includes two side-by-side approx. 60 gallon (useable volume) tanks – one equipped with the high shear LSL mixer and the other equipped with a low-shear propeller mixer (fig. 5).

Figure 5. Commercial pilot mixer equipped with high shear LSL mixer and low shear mixer.

Figure 6. High shear LSL tank interior and mixer blade

The high shear mixer tank in fig. 6 is approximately 35 inches in diameter and 27 inches deep. It utilizes an 11 inch diameter LSL mixer head. The LSL mixer is variable speed, and rotates from 0 to 2250 RPM. For this testing, the mixer was rotated at 1600 RPM (70% power).

Figure 7. Low shear tank interior and paddle mixing blade.

Likewise, the low shear mixing tank is approximately 35 inches in diameter and 27 inches deep. It utilizes a four blade propeller-type mixing blade that is 16 inches in diameter. It operates at a fixed speed of 160 RPM (fig. 7).

Two typical OBM formulations utilizing different oil/water ratios were chosen for pilot mixing in each tank (high shear LSL mixing tank and low shear propeller mixing tank). Table 1 provides the mud formulations that were to be used. However, before beginning the pilot runs on this commercial equipment, it was determined that laboratory tests should first be performed in order to determine the most relevant tests to run on these muds, and the number of samples that would need to be taken as benchmarked against standard low shear and high shear laboratory mixers.

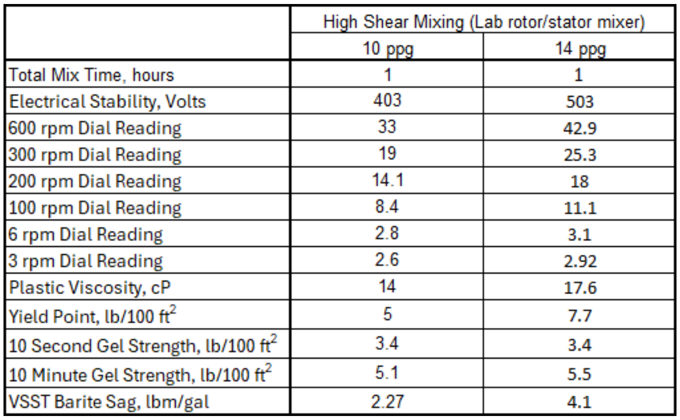
Table 1. OBM Formulations Used in the Study

	10 lb/gal 70/30 OWR	14 lb/gal 80/20 OWR
Diesel, gals	26	24
Organoclay, lbs	4	5
Primary Emulsifier, lbs	3	4
Secondary Emulsifier, lbs	2	3
Lime, lbs	8	10
25% Anhydrous Calcium Chloride Brine, gals	11	6
Wetting Agent, lbs	-	2
Barite 4.10, lbs	110	340

Preliminary Laboratory Testing

Prior to conducting pilot mixing operations, 1750 ml laboratory batches using the formulations identified in Table 1 were prepared under simulated high shear conditions using a standard laboratory rotor/stator-type mixer at 6000 RPM.

Table 2. Laboratory Prepared Mud Properties Using High Shear (Rotor/Stator) Laboratory Mixer



	High Shear Mixing (Lab rotor/stator mixer)	
	10 ppg	14 ppg
Total Mix Time, hours	1	1
Electrical Stability, Volts	403	503
600 rpm Dial Reading	33	42.9
300 rpm Dial Reading	19	25.3
200 rpm Dial Reading	14.1	18
100 rpm Dial Reading	8.4	11.1
6 rpm Dial Reading	2.8	3.1
3 rpm Dial Reading	2.6	2.92
Plastic Viscosity, cP	14	17.6
Yield Point, lb/100 ft^2	5	7.7
10 Second Gel Strength, lb/100 ft^2	3.4	3.4
10 Minute Gel Strength, lb/100 ft^2	5.1	5.5
VSST Barite Sag, lbm/gal	2.27	4.1

This laboratory data was used as a general guide in determining what to expect in the upcoming pilot batches using the LSL mixer.

The tests chosen for this study, and the reasons behind choosing them, are discussed below:

Electrical stability: An OBM emulsion contains dispersed aqueous (brine) droplets within an oil phase. Improved shearing can result in a more uniform emulsion. Since oil is a poor conductor of electricity, a higher voltage required to pass current through the mud is a good indicator of the stability of the emulsion. Since the addition of barite to the mud generally causes an increase in electrical stability, it is helpful to note at what point barite was added when graphing electrical stability versus mixing time.

Rheology: This is the study of fluid deformation and flow characteristics under applied stress. These properties provide a general idea about viscoelastic flow properties which are desired in an OBM. These viscoelastic characteristics are desired to maximize mud pumping efficiency (flow rate vs pressure). Rheology measurements of a low shear stress environment (typically 3 and 6 RPM dial readings) will correlate to the carrying capacity of the fluid system. Typically organoclay is used to provide an increase to the low shear rate viscosity. These treated clays require high shear mixing to promote surface ion exchange, which leads to swelling of the clay platelets. The expansion of the clay platelets will increase the viscosity of the fluid. Therefore, higher viscosity yields can result from improved shear.

Microscopic Emulsion Examination: A stable, high quality emulsion will exhibit very small and uniformly sized droplets. Poor emulsions typically exhibit a wide range of droplet sizes as well as abnormally large droplets. These can be seen clearly under the microscope at 1000X magnification. Well sheared muds typically exhibit superior emulsion structure when viewed through the microscope.

Barite Sag: Due to its high density and large volume in the OBM, barite can begin to settle or "sag" if the oil-based emulsion exhibits poor low-end rheology and gel strength. Sag can cause potential drilling complications such as well-control problems, lost circulation, induced wellbore instability, and stuck pipe (Tehrani-2004). Low shear mud mixing contributes to insufficient rheologies at low RPMs, and the condition can be made worse if the mud has been held static for some time. Sag testing devices measure the initial mud weight of a 10 ml sample, and compare this value to a sample taken near the bottom of the container after 30 minutes of slow mixing. If barite has begun to settle, the difference in weight between the initial and final samples will be significant.

Results of Pilot Batch Testing

Samples of the drilling fluids produced during commercial pilot mixing operations were collected at various intervals for testing in accordance with the lab tests discussed above.

Table 3A: Data Collected From Pilot Batches (1 of 3)

Batch Number	Sample Number	Mud Wt., lb/gal	Mixer Used	Elapsed Time When Sampled, Hours	Temp,˚F	ES, volts
1	1	10	High Shear	0.42	105	80
1	2			0.68	150	354
1	3			1	165	402
2	1	10	Low Shear	1	93.4	32
2	2			2	95.7	33
2	3			3	N/A	56
2	4			4	N/A	53
2	5			5	85	58
3	1	14	High Shear	0.42	102	350
3	2			1.08	165	571
4	1	14	Low Shear	1	71	75
4	2			2	71.7	74
4	3			2.5	74.1	151
4	4			3	86.8	226
4	5			4	90.1	250
4	6			5	92	286
4	7			6	90.4	319

Table 3B: Data Collected From Pilot Batches (2 of 3)

Batch Number	Sample Number	600 rpm	300 rpm	200 rpm	100 rpm	6 rpm	3 rpm
1	1						
1	2						
1	3	45.2	32.8	25.9	19.3	10.1	9.4
2	1						
2	2						
2	3	27.1	13.8	8.3	4.9	1.3	1.2
2	4	30.2	12.5	9.7	5.6	1.3	1.2
2	5	38.1	23.3	14.9	8.9	1.7	1.6
3	1						
3	2	57.8	37.4	29.7	22.4	12.3	11.9
4	1						
4	2						
4	3						
4	4						
4	5	51	28.7	17.9	10	2.2	2.1
4	6	48.5	25.8	16.8	10.2	2.8	2.4
4	7	49.5	26.7	17.8	11.1	3.1	2.8

Table 3C: Data Collected From Pilot Batches (3 of 3)

Batch Number	Sample Number	PV	YP	10-Sec gel	10-min gel	Sag, VSST	Notes
1	1						Last sample prior to adding barite
1	2						
1	3	12.4	20.4	9.5	9.5	0.93	
2	1						
2	2						Last sample prior to adding barite
2	3	13.3	0.5	1.1	1.8	4.78	
2	4	17.7	5.2	1.3	2		
2	5	14.8	8.5	1.9	3.1	4.24	
3	1						Last sample prior to adding barite
3	2	20.4	17	11.9	13.6	1.73	
4	1						
4	2						Last sample prior to adding barite
4	3						
4	4						
4	5	22.3	4.4	3.2	6.7		
4	6	22.7	3.1	3.5	6		
4	7	22.8	3.9	4	7.2	4.33	

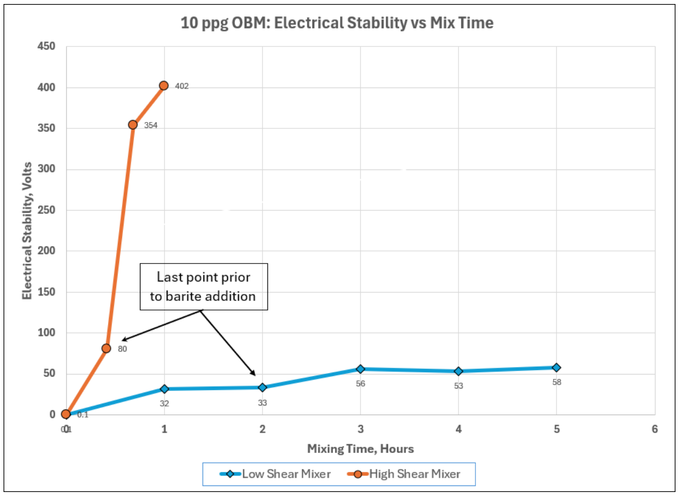


Figure 8. Electrical stability of 10 lb/gal OBM over time

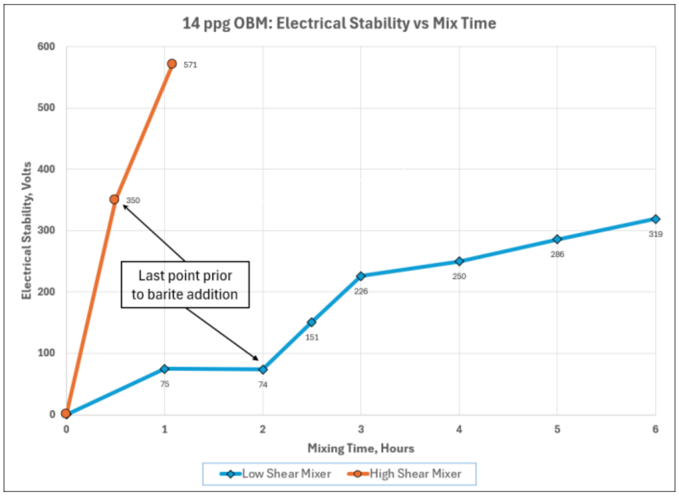


Figure 9. Electrical stability of 14 lb/gal OBM over time

Figures 8 and 9 clearly illustrate the efficiency gains realized by using the LSL high shear mixer as compared with the conventional propeller mixer. In one hour the LSL high shear mixer reached an electrical stability of 571 volts in the 14 lb/gal OBM and 402 volts in the 10 lb/gal OBM, as compared with 319 volts in 6 hours and 58 volts in 5 hours, respectively, using the low shear mixer.

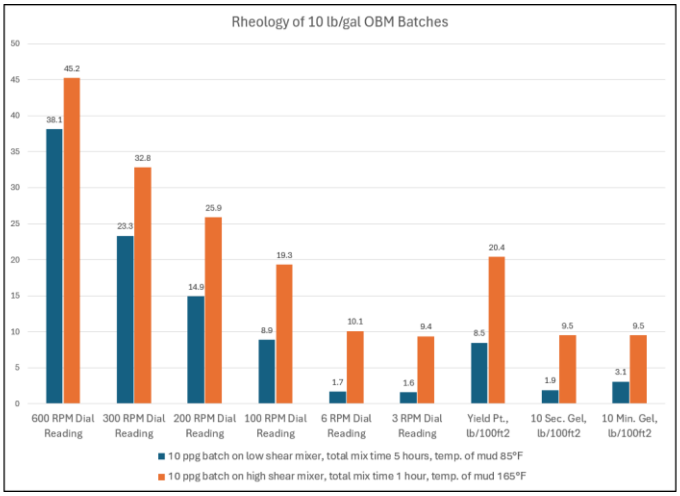


Figure 10. Rheology of 10 lb/gal OBM batches
All rheological data run at 150°F.

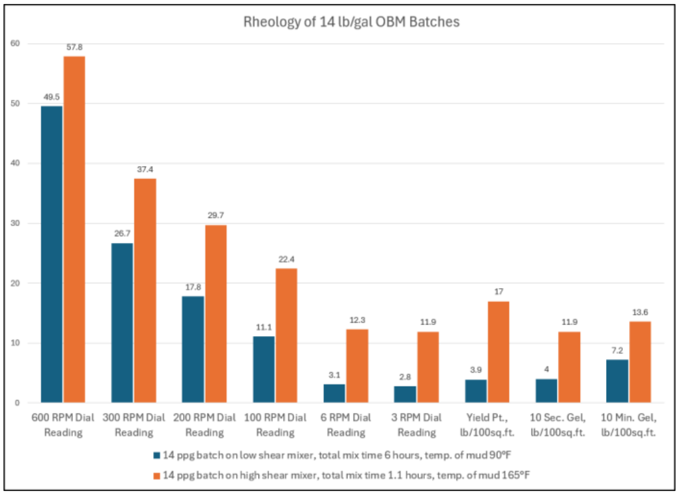


Figure 11. Rheology of 14 lb/gal OBM batches
All rheological data run at 150°F.

Figures 10 and 11 show that rheological properties for the 10 and 14 lb/gal OBMs are consistently higher for the muds prepared on the LSL High Shear mixer, as compared with the Low Shear propeller mixer.

It is interesting to note that the LSL high shear mixer generates significantly higher temperatures in a much shorter time than the low shear mixer. For both the 10 lb/gal and 14 lb/gal OBMs, the LSL high shear mixer reached 165°F after approximately one hour, whereas after five to six hours the low shear mixer reached at best 90°F. This illustrates another advantage of the LSL high shear mixer, since higher temperatures facilitate dispersion of the chemical components into the mud.

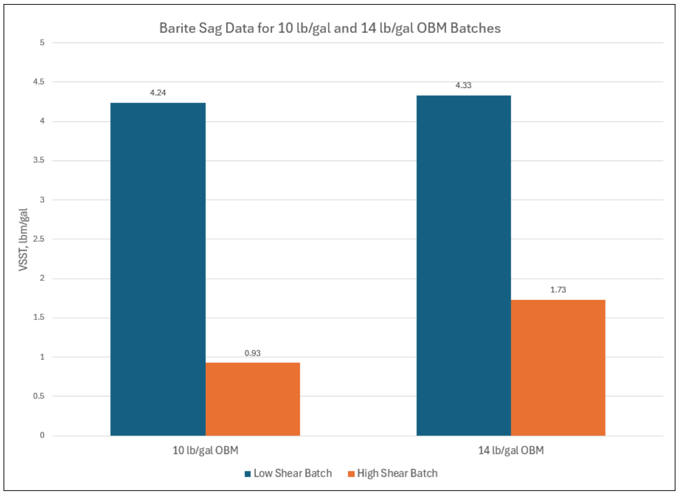


Figure 12. Barite sag test results on 10 and 14 lb/gal OBMs

Sag VSST values reflect the difference in density of the mud initially and after a 30 minute rest period. The higher the number, the greater the sag. It can be seen from fig. 12 that barite sag values are significantly higher for the low shear mixer batches at both 10 and 14 lb/gal, indicating a higher mud density at the bottom of the test containers. This is an indication that the barite has begun to settle due to insufficient mixing of the OBM.

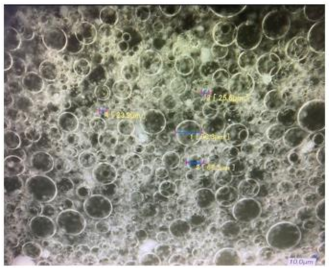


Figure 13
Low shear

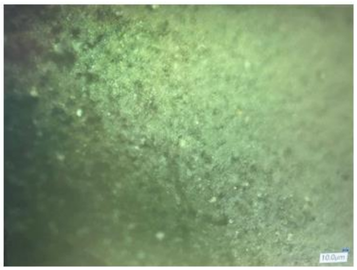


Figure 14
High shear

Both photos are for the 10 lb/gal OBM prior to barite addition at 1000X Magnification

A more stable or "tight" emulsion will contain small droplets uniform in diameter. The Low-shear emulsion structure (fig. 13) is "loose" and the droplets vary in diameter and overall size distribution. The high shear emulsion structure (fig. 14) is "tight". The droplets have a smaller diameter and are more uniform in size.

Conclusions

Through rigorous oilfield testing it was determined that the implementation of an LSL concept can drastically reduce mix time, increase internal heat generation, and improve fluid system quality. Liquid Shearing Liquid is accomplished via meticulous mechanical design and cannot be achieved via conventional low shear mixing systems. This LSL design significantly impacted mixing times, which resulted in an 82% mix time savings. In a side-by-side comparison with conventional low shear mixing, the LSL concept exhibited superior mud characteristics in terms of electrical stability, low end rheology, and reduced barite sag.

The widespread implementation of this novel LSL mixing technology could have a significant positive impact on the ability of drilling fluid suppliers to provide high quality muds to the well site in a fraction of the time, with chemical properties certain to meet operators' needs without having to depend on circulation through the drill bit nizzle to achieve expected fluid characteristics.

Further Investigation

A worthwhile follow-up pilot run would evaluate the same 10 lb/gal and 14 lb/gal mud formulations using a larger LSL high shear mixer (450+ BBLs) in order to judge scalability.

A companion investigation would look into potential cost savings made possible by using smaller quantities of mud components sheared more efficiently into the OBM to achieve similar properties.

Finally, a similar study of water-based muds (WBM) would further illustrate the advantages of using the LSL high shear technology.

Acknowledgments

The authors would like to thank Chemjet, Inc, and Bard & Bard LLC management for their support, including the use of commercial mixing equipment and assignment of additional laboratory personnel required to perform this study.

Nomenclature

API = *American Petroleum Institute*
BBL = *barrel (42 gallon)*
ES = *Electrical Stability*
LSL = *Liquid Shearing Liquid*
OBM = *Oil Based Mud (Drilling Fluid)*
LB/GAL = *Pounds Per Gallon*
PV = *Plastic Viscosity*
RPM = *revolutions per minute*
VSST = *Viscometer Sag Shoe Test*
WBM =*Water Based Mud (Drilling Fluid)*
YP = *Yield Point*

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