AADE-16-FTCE-78

Automated Particle Size Analysis using Advanced Analyzers

Besmir Buranaj Hoxha, Lin Yang, Arthur Hale, and Eric van Oort, The University of Texas at Austin

Abstract

Novel measurement tools and techniques are now making it possible to carry out sophisticated drilling fluid analyses using largely automated equipment. This paper anticipates and highlights the important role that automated particle size analyzers will play in future drilling operations.

A comprehensive experimental study was carried out using a new generation of particle size analyzers (PSA) to investigate their utility for automated drilling fluid analysis. The analyzers that were evaluated were the Canty Microflow LPA, the Mettler Toledo G400 ParticleTrack, and the Malvern Mastersizer and Zetasizer. These instruments were used in conjunction with in-house flow loops and shearing facilities to test (1) degradation of the particle size distribution (PSD) of lost circulation and wellbore strengthening materials under the influence of shear, (2) the behavior of the emulsion droplet size distribution (DSD) of invert emulsion mud systems (oil-based and synthetic-based muds – OBM/SBM) under a variety of influences including shear and temperature, change of oil-water ratio (OWR), mud treatments, etc.

The results show that the PSDs of LCM materials is far from stable and degrades over time, primarily due to the influence of shear. It will be shown that automated, inline PSA equipment allows for the degradation to be monitored and managed in real-time to maintain optimum drilling performance. In addition, such equipment can be used to monitor and optimize the DSD of an invert system, which is an important quantity that influences mud performance characteristics such as rheology, emulsion stability, fluid loss behavior, osmotic membrane efficiency, etc.

Introduction

This paper looks into PSD analysis using sophisticated PSAs of two favorite materials used for fluid loss control and wellbore strengthening purposes: calcium carbonate and graphite. As we will show in the remainder of this paper, both materials in regular size range (D50 ~ 250 - 400µm) undergo size degradation as a function of applied shear. Interactions with pumping and mixing elements, collisions with pipe walls and between particles, shearing through bit nozzles, etc. will eventually transform an initial optimum PSD into a suboptimum one. Shear degradation therefore poses a significant technical challenge in actual field operations, given the importance of maintaining an optimum PSD for effective fluid/fracture loss control purposes. Moreover, mud engineers in the field currently manage PSDs using largely empirical criteria on LCM additive consumption, usually guided by nothing more than a “sacks per hour” addition rate. They may be aided by manual sieve analysis of mud samples, but this is labor-intensive and time-consuming. Here, the use of in-line and largely automated PSAs could make a big difference in improving optimum PSD management.

In addition, we study the PSD behavior of the DSD of an SBM by looking at the effects of shearing, changes in the OWR, changes in product concentration, and addition of fluid additives such as emulsifiers. Three techniques (see Table 1 and Figure 1) were used for our PSA study:

Laser diffraction, as used in the Malvern Masterizer and Zetasizer equipment, is a popular lab-based particle sizing technique due to its fast operation and reliable results. The laser light is passed through a sample cell filled with dispersed particles. The particles have to be dispersed in water or other solvent (air, alcohol, etc.). Particles diffract the incident light at various angles based on their diameter. The detector then captures the intensity of the diffracted light, which is correlated with the PSD. The output from laser diffraction is expressed as equivalent spherical diameters. The concentration of solids should be adjusted through dilution to allow light to pass through the sample.

Focused beam reflectance measurement (FBRM) technology utilizes probes that can be directly inserted into the mud stream, i.e. measuring undiluted mud. FBRM is used in the Mettler Toledo ParticleTrack equipment: a G400 instrument was used here. It provides real time insight into mud particle dimension and relative particle count, without the need for sampling or sample manipulation. Briefly, 780nm monochromatic laser light is focused close to a synthetic sapphire probe window that is in direct contact with the drilling mud. As mud particles flow across the probe window, they backscatter light. The measurement system can identify how long any particle has been in contact with the laser beam based on the back-scattered laser pulse (Allen, 1996). The FBRM probe detector converts backscattered laser pulses into a chord length, defined as a line segment connecting any two points on the boundary of a particle. Thousands of individual chord lengths can be characterized in an instant, thereby providing a real time chord length distribution. This distribution provides a characteristic 'fingerprint' of a mud’s particle system that allows users to detect and monitor changes in particle dimension and count in real time.

Optical microscopy and electron microscopy, supplemented with sophisticated image analysis techniques, can be used to determine particle size. Since the method has to be compatible with analyzing drilling fluids, optical microscopy will be more practical. In our PSA studies, we used Canty Microflow LPA optical microscopy equipment. Optical microscopy usually has a lower detection limit of ~1.0 µm and no upper limit in theory. The camera captures a visual image of the sample with dispersed particles and determines the particle size with advanced image analysis algorithms. Such image analysis can provide multiple size-related particle parameters (e.g. longest and shortest diameter, perimeter, projected area, equivalent spherical diameter, aspect ratio and circularity), giving it an advantage over other techniques when characterizing irregular particles. However, due to its small depth of focus, it has difficulty in capturing all the particles from a sample with a wider PSD, and generally requires dilution in order to deal with opaque fluids. This may be a concern when studying the DSD of OBM/SBM in particular, where dilution will affect the OWR which in turn may affect droplet size. The effect of dilution on the DSD of OBM/SBM was therefore a specific topic of investigation in this study.

Table 1 – Comparison of three commercial Particle Size Analyzers (PSA).

	Malvern Mastersizer & Zetasizer	**Canty Microflow LPA**	**Mettler Toledo G400**
Technique	Laser Diffraction	Microscopy & Image Analysis	FBRM
Size Range	0.02 – 2000 µm	Larger than 1 µm	0.5 – 2000 µm
Measured Particle Size	Equivalent spherical diameter	Minor axis	Chord length
PSD Type	Volume weighted	Count-weighted converted to volume weighted	Unweighted and Square-weighted
Dilution Required?	Yes	Yes	No

Experimental

Figure 1 shows schematics of the PSA techniques. A detailed description of each technique is given elsewhere (van Oort et al., 2016). Commercial LCM grades of medium and fine sized calcium carbonate and graphite were used in the size degradation tests. Glass microspheres were used as a reference material in the experiments. These spheres are more shear resistant than calcium carbonate and graphite, with a hardness of 6 on Mohs hardness scale, while the hardness values are 3 for calcium carbonate and 1 for graphite.

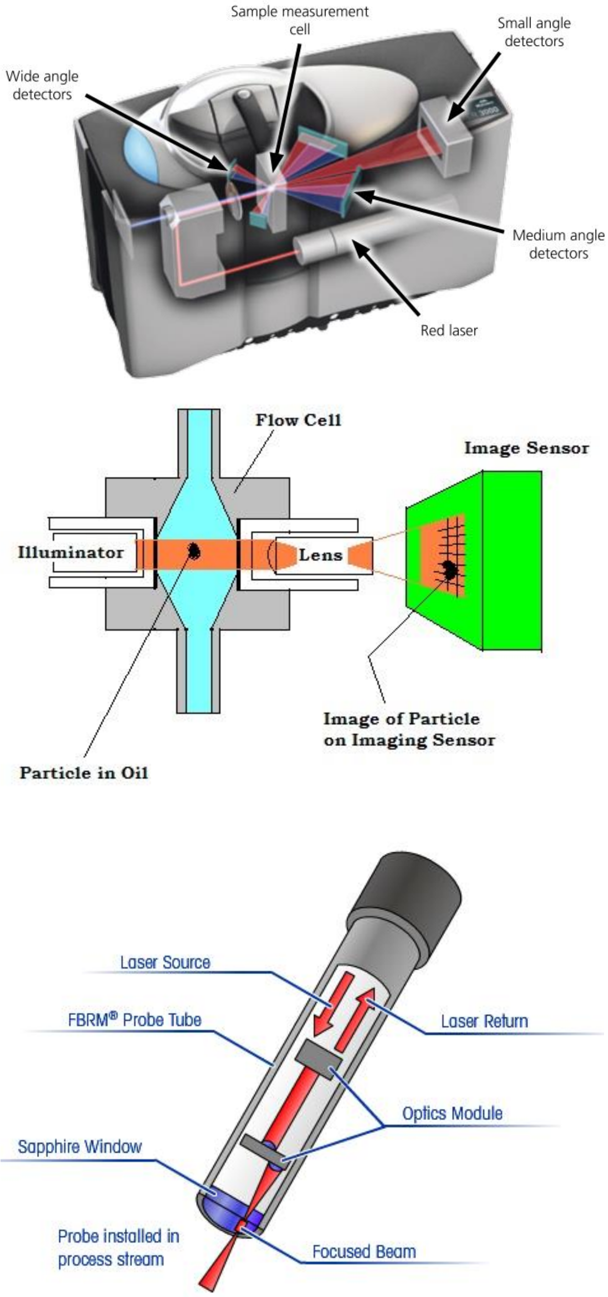

Figure 1 – Schematics of three commercial Particle Size Analyzers (PSA): (top) laser diffraction as used in Malvern Mastersizer / Zetasizer (image courtesy Malvern); (middle) optical microscopy, as used in Canty Microflow LPA (image courtesy Canty); (bottom) FBRM, as used in Mettler Toledo ParticleTrack G400 (image courtesy Mettler Toledo).

The WBM system used was a simple unweighted mud system that was viscosified with 1.5 ppb Xanthan Gum. The SBM system, generously provided by Baker Hughes, was a 12 ppg formulation with an OWR in the range 60/40 – 99/1, with a typical 70/30 – 80/20 formulation as specified in Table 2.

Table 2 – 12 ppg SBM formulation (based on C14-C20 Internal Olefin (IO)	
OWR	70/30 – 80/20
Primary Emulsifier (Polyamide)	3 - 12 ppb
Secondary Emulsifier (Fatty Acid)	< 1 ppb
Lime	3 - 5 ppb
Organophilic Clay	3 ppb
Brine	25% wt CaCl2
Density (weighted with barite)	12 ppg

Results and Discussion

Particle Size Analysis and Degradation Results

PSA and degradation results discussed below are highlights of a more extensive investigation, which is discussed in more detail elsewhere (van Oort et al., 2016)

Glass Spheres Reference Material

Results of PSA investigation on glass spheres reference material are given in Table 3, showing the D10, D50 and D90 values obtained from each PSA with the inclusion of published literature data for the material as well as the results of our own sieve analysis. All PSA results were very close to literature and sieve analysis values for D50, with variation less than 5%. This is an encouraging result that attests to the quality of the instruments. The largest variation in D10 and D90 values was seen with the MT equipment, showing some limitations of the chord length approach for glass spheres, which is smooth and highly reflective. Measuring chords, it can be easily explained why the measurement gives lower D10 values even for highly spherical particles; the higher D90 values may result from nearby particles overlapping with each other in the undiluted samples measured by the MT equipment. D10 and D90 variations observed by Malvern and Canty equipment are within a similar range.

Table 3 - Comparison between the literature data (Cospheric, 2014) and the measurements from sieve analysis, Canty, Malvern and MT for glass microspheres in terms of D10, D50 and D90 values.

	D10, μm	D50, μm	D90, μm
Literature Data	48.0	69.0	83.0
Sieve Analysis	56.8	69.7	84.9
Canty	60.8	71.7	87.8
Malvern	52.2	71.5	98.0
MT	22.4	72.4	121.6

Calcium Carbonate Results

Tables 4 & 5 show the PSA results obtained for calcium carbonate fine and medium respectively. The discrepancy between literature data and sieve analysis results for calcium carbonate fine indicates that the size of the product is either not controlled properly or changes significantly upon handling. This may have important field implications, as the calcium carbonate fine material that is actually mixed into the mud may be quite different from what is reported in literature. Calcium carbonate regular apparently has better quality control.

Table 4 shows that the calcium carbonate fine measurements from MT agree well with the sieve analysis results on D10 and D50. D90 obtained using MT (467 μm), however, is significantly higher than the value obtained from sieve analysis (165 μm), and may again result from nearby particles overlapping with each other / clumping together, in the undiluted samples measured by the MT equipment.

Measurements from Canty and Malvern for calcium carbonate fine are consistently lower than the sieve analysis results. This, however, may be more of an issue with the sieve analysis that with the PSA equipment. The consistency between Canty and Malvern might indicate that small clumps of calcium carbonate were present at the end of sieving. The vibration applied by sieve shaker may not have been enough to separate individual calcium carbonate particles, especially for smaller particles (5-50 μm), while the dilution and mixing provided by Canty and Malvern equipment helped to separate particles effectively. Hence, we believe that Canty and Malvern equipment provide a more accurate reflection of the true PSD for calcium carbonate fine in solution.

For calcium carbonate regular, measurements (Table 5) from the three PSAs follow a similar trend, with a higher D90, lower D10 and similar D50 compared with the results obtained using sieve analysis. Note that D50 values are all in very good agreement with published data and sieve analysis.

Table 4 - Comparison between literature data (D. Clapper, personal communication) and measurements from sieve analysis, Canty, Malvern and MT for calcium carbonate fine in terms of D10, D50 and D90 values.

	D10, μm	D50, μm	D90, μm
Literature Data	-	150	-
Sieve Analysis	25	58	165
Canty	13	25	130
Malvern	4	17	77
MT	19	59	467

Table 5 - Comparison between literature data (D. Clapper, personal communication) and measurements from sieve analysis, Canty, Malvern and MT for calcium carbonate regular in terms of D10, D50 and D90 values.

	D10, μm	D50, μm	D90, μm
Literature Data	-	250	-
Sieve Analysis	110	230	338
Canty	60	244	446
Malvern	67	277	508
MT	55	219	468

Using in-house flow loop and shearing facilities (van Oort et al, 2016) it was possible to study the shear degradation behavior of calcium carbonate in solution. Negligible degradation was observed for calcium carbonate fine. However, regular calcium carbonate showed significant size reduction when sheared moderately (See Figure 2), with D50 values decreasing by 25% - 40% after 30 mins of shearing, in good agreement with results previously reported (Scott et al., 2013; Kumar et al., 2014). Note that all PSA equipment was in good agreement regarding the shear degradation trend and absolute values. A clear added benefit of the MT equipment is that it can provide this important mud maintenance information in real-time with an in-line measurement working on undiluted mud, as shown in Figure 3.

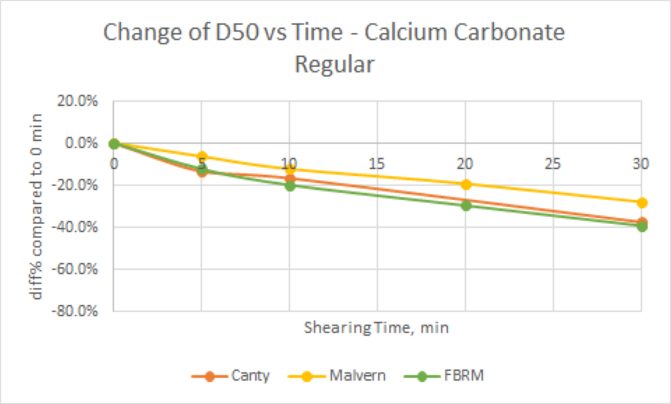

Figure 2 – Changes in the value of D50 of calcium carbonate regular with increasing shearing time, according to measurements by Canty, Malvern and MT PSAs. Note that all PSAs show a similar, gradual reduction in D50 value.

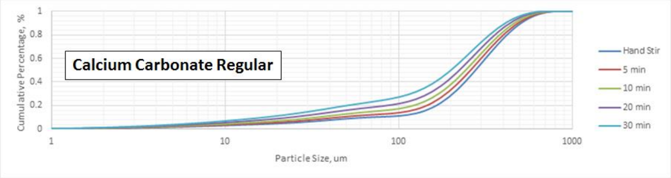

Figure 3 – Change in D50 value of calcium carbonate regular as a function of time, as recorded in real-time in undiluted mud by MT equipment.

Graphite Results

The PSA results for graphite fine and graphite regular are given in Tables 6 and 7 respectively. There is generally good agreement between the sieve analysis and the literature data for both materials. The Canty equipment shows the highest degree of quantitative agreement with the published and sieve results, and clearly stands out among the three PSAs tested. The MT equipment performs much better on the graphite fine material than the graphite regular material. This again can be understood in term of the chord length approach: graphite is an irregularly shaped material, and for larger particles it is quite possible to measure small(er) chords along minor axes across the materials – hence the larger deviation of the D10 value. The Malvern equipment shows relatively large deviation on the graphite fine material, and smaller deviation on the graphite regular material. This also can be understood by considering that the graphitic material is irregularly shaped while the Malvern technique relates all measurements back to a sphere of equivalent volume: the percentage error for a smaller graphite particle in this case is larger than for a larger particle.

Similar to calcium carbonate, shear degradation results were obtained for graphite. Graphite fine was found to be stable in size under conditions of moderate shear, with negligible change in D50 values over time. Graphite regular, however, was found to degrade to a degree similar to carbonate regular (see Figure 4 and 5). This is a distinctly different from those obtained previously (Scott et al., 2013; Kumar et al., 2014), showing graphite to be relatively stable and insensitive to shearing. The D50 reduction values obtained from MT show a much larger reduction in size compared to those from Malvern and Canty. This might again be because the particle size measured using MT is the chord length of the particles, making MT's equipment more sensitive to changes in the particle size as particle shape becomes more irregular. Better calibration of the MT equipment for irregularly shaped particles appears to be warranted. The Canty and Malvern measurements are in good agreement, showing a reduction in D50 in the range 20 – 35% after 30 mins of shearing. An important advantage of the MT equipment again is that the size degradation can be quantified in real-time on undiluted mud (Figure 5), with evident benefits to mud maintenance.

Table 6 – Comparison between literature data (D. Clapper, personal communication) and measurements from sieve analysis, Canty, Malvern and MT for graphite fine in terms of D10, D50 and D90 values.

	D10, µm	D50, µm	D90, µm
Literature Data	27	112	287
Sieve Analysis	42	101	223
Canty	38	92	181
Malvern	11	66	215
MT	33	83	178

Table 7 – Comparison between literature data (D. Clapper, personal communication) and measurements from sieve analysis, Canty, Malvern and MT for graphite regular in terms of D10, D50 and D90 values.

	D10, µm	D50, µm	D90, µm
Literature Data	211	370	634
Sieve Analysis	226	361	628
Canty	230	358	546
Malvern	271	474	781
MT	48	177	501

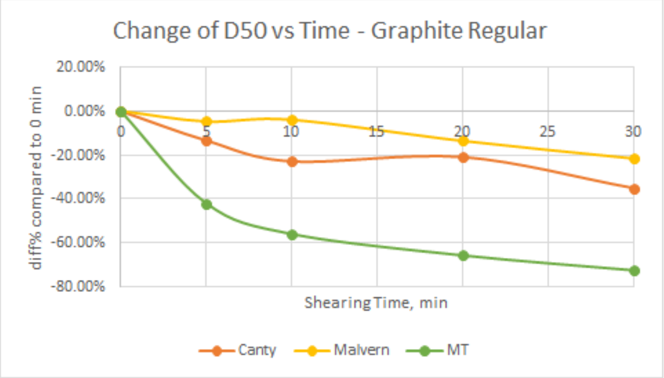

Figure 4 – Changes in the value of D50 of graphite regular with increasing shearing time, according to measurements by Canty, Malvern and MT PSAs. Note that the size reduction recorded by the MT equipment is significantly larger than what is reported by the other PSAs.

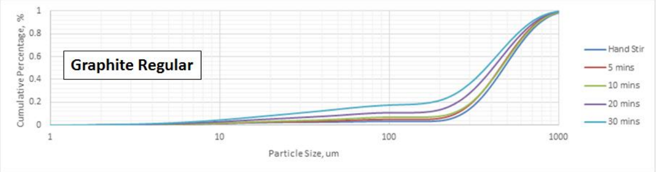

Figure 5 – Change in D50 value of graphite regular as a function of time, as recorded in real-time in undiluted mud by MT equipment.

SBM Droplet Size Distribution Analysis Results

Canty equipment was used almost exclusively for the SBM DSD analyses below, unless otherwise stated. Mettler Toledo equipment can be used for simple invert emulsions of water emulsified in (synthetic) oil, but only when the emulsion droplets where the only particles present in an unweighted fluid. The Malvern ZS equipment unfortunately gave inconsistent DSD results, and was used only for zeta potential (ZP) measurements. Optical microscopy with image analysis, however, proved to be a reliable way to characterize droplet distributions with good reproducibility and without artifacts. Prior to testing on emulsion droplets, the Canty equipment was calibrated with reference materials. Iso-dust, micro-spheres and barite were all used for the calibration purposes in comparisons with dry sieve and wet sieve analyses. The Canty equipment showed accurate results with all calibration materials. Additional calibration involved calibrating the camera to ensure the pixel scale factor is accurate. A special analysis tool was used (Canty Vision Droplet & Emulsion Tool), specifically designed to measure emulsions. Prior to analysis with this tool, further calibration was performed to ensure an accurate measurement with appropriate scaling.

It should be noted that the work reported in the following is preliminary, and serves the purpose of demonstrating a proof-of-concept of what is now possible in terms of in-depth monitoring of (the quality of) OBM/SBM invert emulsions.

Effect of Dilution

To obtain clear images for analysis, the Canty equipment dilutes mud samples by a ratio of up to 30:1 with base fluid (water for WBM, (synthetic) oil for OBM/SBM). The dilution with water for WBM does not appear to pose any problems, but dilution with (synthetic) oil does change the OWR of OBM/SBM. The Canty Auto Dilution Function was therefore thoroughly investigated to determine whether it altered the DSD. Undiluted mud samples were initially measured via gravity feed and afterwards dilution was initiated via a pump. Image analysis was recorded to show the dilution transitions of the sample. Subsequently, in-depth measurements of the emulsion droplets were conducted through the use of special emulsion tool analysis.

Typical results are shown in Figure 6, including the DSD obtained for diluted and undiluted samples. These were found to be nearly identical, indicating that dilution did not measurably affect the DSD. The reason for this is most likely the low mixing energy associated with dilution: mixing at typical flow rates of 500 mL/min and 840 mL/min occurred at Reynolds numbers of 144.5 and 243 respectively, i.e. well within the laminar flow region. Apparently, at these flow rates and with the short time delay associated with obtaining droplet images, the invert emulsion DSD is not significantly altered.

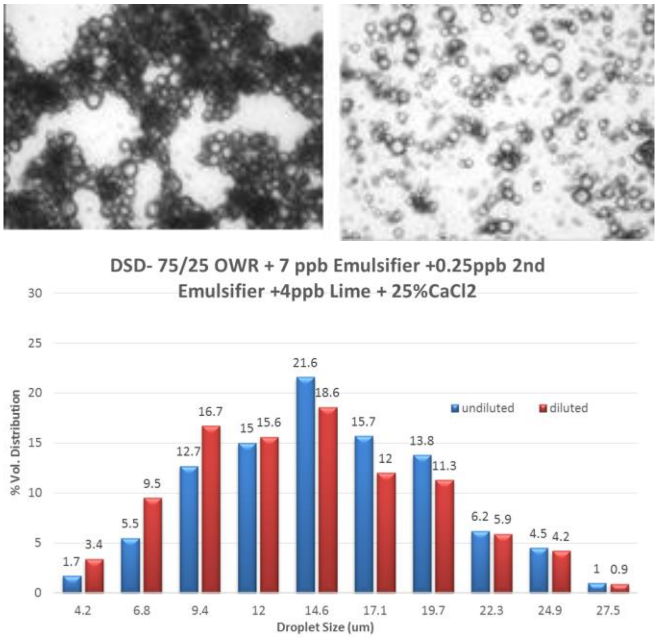

Figure 6 – (top left) image of undiluted SBM; (top right) image of diluted SBM; (bottom) DSD of undiluted and diluted mud samples

Figure 7 below shows other important requirements for proper emulsion analysis: recognizing weighting material particles (barite) and air bubbles entrapped in the fluid. The former can be distinguished based on their irregular shape compared to emulsion droplets; the latter are usually much larger than invert emulsion droplets. The image analysis software is able to distinguish both.

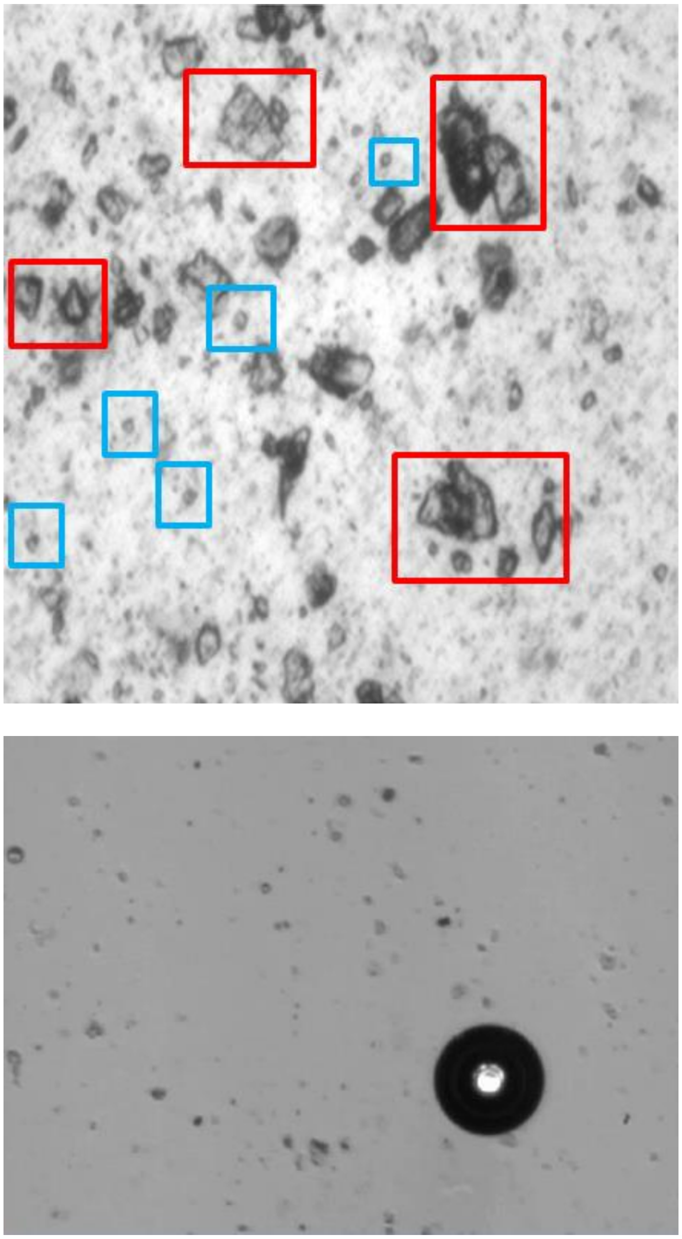

Figure 7 – (top) SBM image with identification of emulsion droplets (blue squares) and barite particles (red squares); (bottom) SBM image showing a large air bubble among smaller droplets and weighting materials.

Effect of OWR

Table 8 and Figure 8 show DSD variation as a function of OWR while keeping the emulsifier concentration constant at 3 ppb. Table 8 does not include the results of several attempted experiments with MT G400 and Malvern ZS equipment, which were inconclusive for reasons mentioned above. Only the Canty equipment was able to clearly distinguish the pattern of increasing droplet size with increase of water fraction (= decrease in OWR) with images that allowed for clear verification and avoidance of test artifacts.

Table 8 – DSD D50 (in μm) for variation of OWR

	99/1	90/10	80/20	75/25	70/30	60/40
Canty	13.2	13.5	15.2	15.1	18.4	24.0

Effect of Emulsifier Additions

Emulsifiers are amphiphilic (polar hydrophilic head and nonpolar lipophilic tail) organic compounds, which reduce the interfacial tension between the dispersed phase (water) and the continuous phase ((synthetic) oil) (see e.g. Evans, 2000; Young, 2012). By doing so, they are able to modify the interface of the otherwise immiscible phases and allow them to mix. The primary emulsifier used in this study was a polyamide surface acting agent (surfactant) that adsorbs onto the liquid-liquid interface to form an interfacial film/emulsion layer, and a secondary emulsifier (fatty acid derivative) was used as a wetting agent to disperse solids into the oil phase. Various emulsifier concentrations were investigated together with the addition of the secondary emulsifier. Product concertation of the primary emulsifier was studied at 3, 7, and 12 ppb, with the secondary emulsifier added at 0.25 ppb.

As can be seen from Figure 9, as the emulsifier concertation increases, the average droplet size characterized by its D50 value decreases. Clearly, when emulsifier levels increase, larger emulsion bubbles appear to break down into more stable smaller bubbles, with the additional surface area thus generated covered by the increased emulsifier concentration (Al-Mutairi, 2009). There comes a point, however, where the emulsifier concentration is at optimum for a given OWR. Excess emulsifier will either dissolve in the continuous phase, forms flakes in the solution, adsorb onto interfaces, or even possibly form micelles. In our DSD analysis, we have seen the occurrence of a peak at ~400μ, which increases with increasing excess of emulsifier in the SBM. The peak is attributed to flakes of excess emulsifier.

Note that is common field practice to “overtreat” SBMs with emulsifier in order to handle e.g. water-wetting of drilled solids and/or formation water/brine influxes (Growcock et al., 1994). Using the PSA techniques described here, it is now possible to properly monitor and regulate emulsifier treatment, with associated drilling fluid optimization and cost savings.

Effect of Shearing

It is well-known that the emulsion droplet size has a strong influence on mud rheology as well as fluid loss control. Essentially, tight emulsions with smaller droplet sizes are more stable and deliver higher viscosity than loose emulsions with larger droplet sizes (see Figure 8). If the total volume fraction of the emulsion in the mud is kept constant, and a shift in coarse emulsion droplets to finer emulsion droplets can be achieved with a narrowing of the size distribution, e.g. by shearing the fluid, the result will be an improvement in rheological properties of the mud. This in itself is nothing new, but our study is one of the first where the impact of shearing on the SBM emulsion was directly observed and quantified.

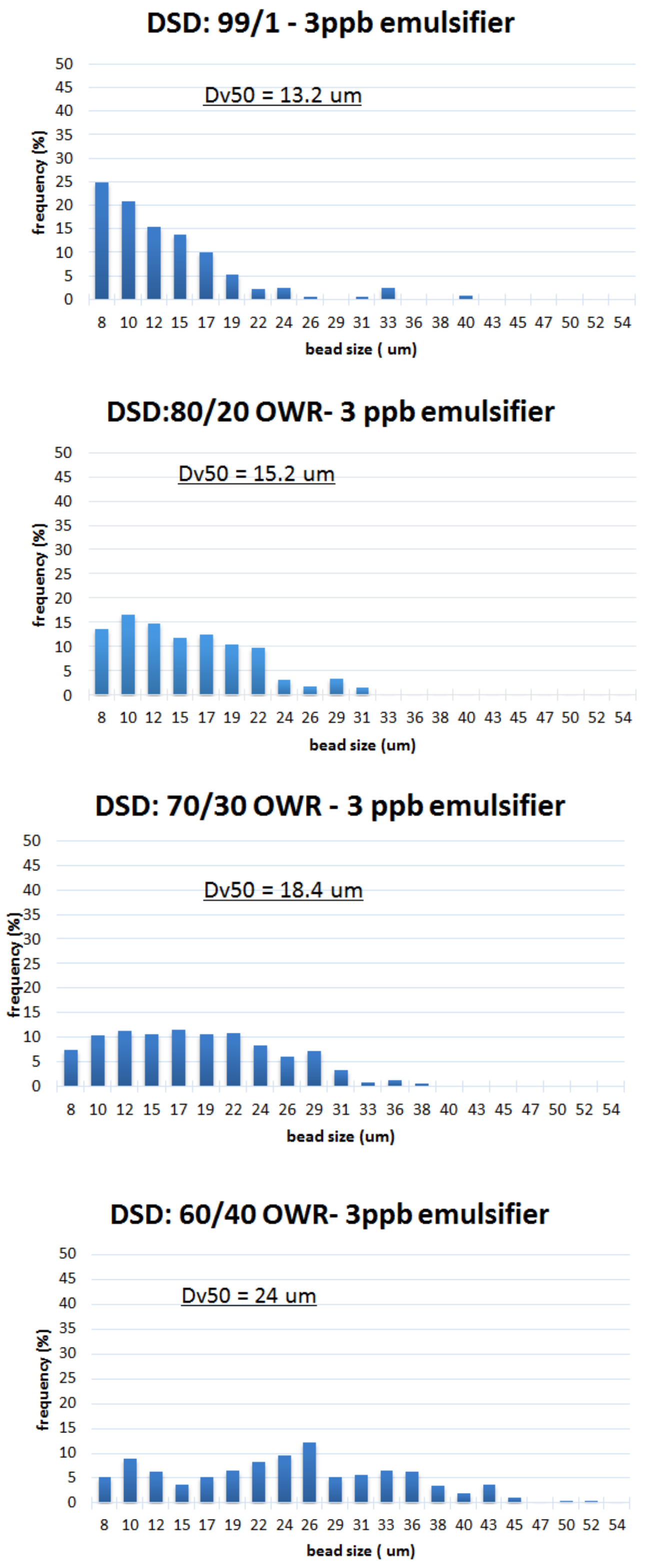

Figure 8 – Evolution of SBM DSD as a function of OWR (as indicated) for a constant emulsifier concentration of 3 ppb. In addition to the change in D50 value, note the change in the DSD profile.

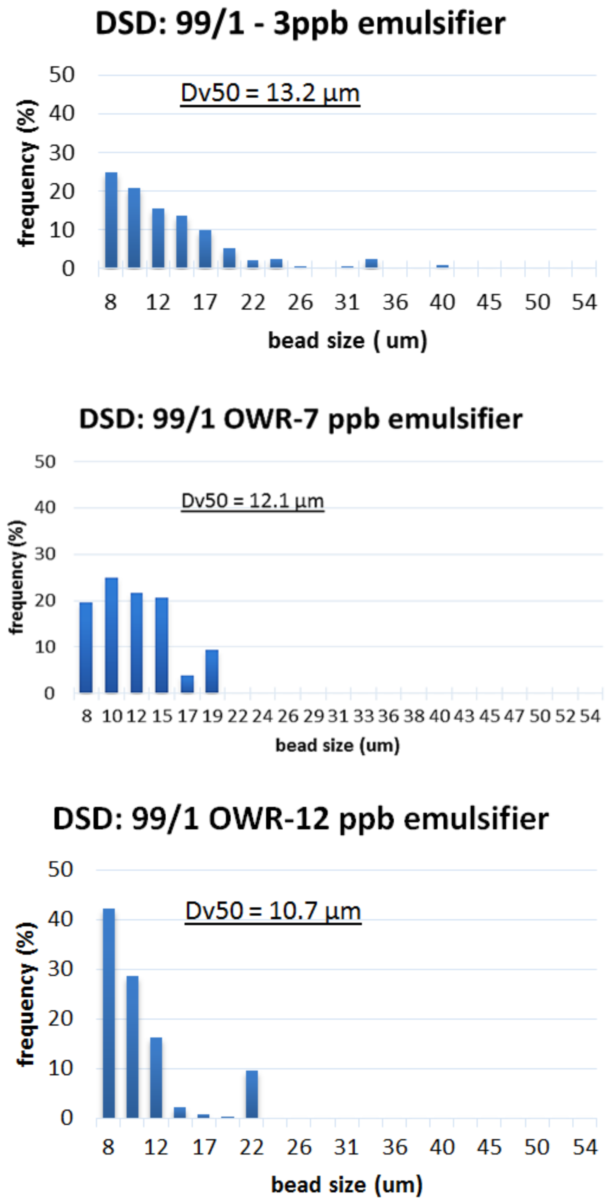

Figure 9 – SBM DSD at 3, 7 and 12 ppb primary emulsifier concentration, measured with Canty equipment. Note the shift in D50 to lower values with increasing emulsifier concentration.

A simple experiment was performed where the DSD of the 12 ppb SBM was studied as a function of shearing. Mud samples were built using a Silverson mixer (using its polymer square head) that can achieve high shear stress. A formulation of 75/25 OWR with 7 ppb emulsifier was selected. Muds were built over a period of 25 mins while shearing the fluids for a total of 10 mins at 2500 rpm and 4000 rpm. The DSD of the muds were recorded thereafter. The results are shown in Figure 10 below.

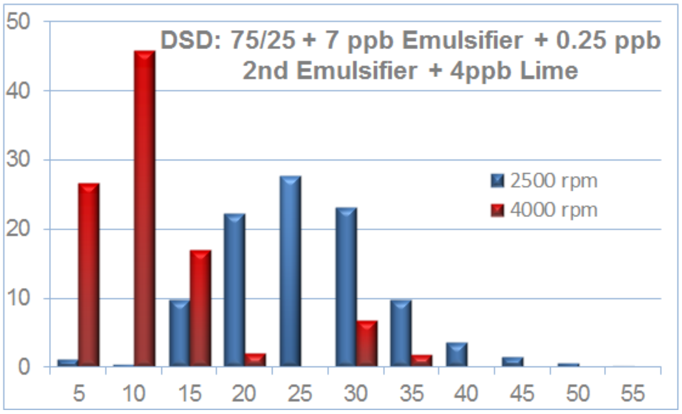

Figure 10 – SBM DSD after preparing and shearing the fluid at 2500 rpm and 4000 rpm.

Figure 10 shows that shearing the SBM at the higher shear rate creates an emulsion with smaller emulsion droplets and a narrower distribution. This result is actually very comparable to addition of additional emulsifier (e.g. going from 7 ppb to 12 ppb) as shown in Figure 9. Clearly, the higher shear rate makes the emulsifier action more effective at lower concentrations. Again, this is not unexpected, but the DSD measurement allows quantification/visualization of the effect.

In discussing the effect of shear, it is interesting to highlight the functionality to measure ZP offered by the Malvern Zetasizer. This was done for a 90/10 OWR SBM that was sheared for 5 mins at 2000 rpm and 6000 rpm. The results are shown in Table 9. With the Zetasizer, we were able to get reliable ZP values, which were significantly higher at the higher shear rate. It is known (Morrison and Ross, 2002; Sjoblom, 2001) that at ZP values around 25mV to 30mV, the repulsive forces between droplets exceed their attractive forces, such that the emulsion droplets remain dispersed and the overall emulsion is relatively stable (see Table 10). From our experiments, at ZP values less than 25mV the attractive forces are apparently overcoming the repulsive forces and the emulsion droplets will begin to couple and aggregate.

The implications of this preliminary work are rather profound. Using DSD analysis and ZP measurement in addition to traditional ES measurements, which all can be automated, it is possible to optimally maintain an invert emulsion, using shear imparted to the fluid by the drilling process itself and by additional shear that can be provided by dedicated shearing units. This, in turn, has the potential to optimize SBM product additions and avoid unnecessary excess treatments of the mud, resulting in cost savings. The opportunity to achieve such savings will be studied in future.

Table 9 – Shearing effect on emulsion electrical stability (ES) and zeta potential (ZP).

Shearing RPM (Silverson, 5 min mixing)	2000	6000
Mud temperature after mixing (^{o}F)	72	85
Electrical Stability - ES (mV)	281	610
Zeta Potential ZP (mV) – Malvern ZS	12.9	33.7

Table 10 – Stability behavior of emulsions as a function of their ZP (Morrison and Ross, 2002)

Zeta Potential (mV)	Stability Behavior
0	Total Phase Separation
0 to ± 5	Rapid Aggregation / Coalescence
± 5 to ± 25	Low Stability
± 25 to ± 40	Moderate Stability
± 40 to ± 60	High Stability
> ± 60	Superior Stability

PSA Automation

The results reported above offer at least two compelling reasons to measure fluid PSDs and OBM/SBM DSD's in an automated way in real-time: (1) real-time monitoring and control of LCM PSD and degradation to optimize fluid loss / lost circulation control and wellbore strengthening; (2) real-time monitoring and control of the quality of OBM/SBM emulsions in order to optimize them with minimum chemical usage. At the time this paper was compiled, the only viable candidate (see Figure 11) for automated field application was the G600 Ex Mettler Toledo ParticleTrack instrument with appropriate certifications for field use (ATEX, Class 1 Div 1). In fact, this instrument has already been applied in the field for LCM PSD monitoring purposes by Ronaes et al. (2012). Canty is currently in the process of testing an in-line, field certified optical monitoring system with a cross-cut sampling valve for quick and repeatable fluid sampling from the mud stream.

Figure 11 – PSA systems for real-time, automated monitoring in the field: (top) MT G600 Ex (image courtesy Mettler Toledo; (bottom) Canty In-Line Drilling Fluid System (image courtesy JM Canty).

Conclusions

In this paper, we have used three commercially available PSAs, namely Canty LPA, Malvern Mastersizer 2000 / Zetasizer and Mettler Toledo ParticleTrack G400 to characterize PSDs of calcium carbonate and graphite, two favorite materials for lost circulation control and wellbore strengthening, as well as to investigate DSDs of SBM. Our conclusions are as follows:

- Optical microscopy with image analysis using Canty equipment produced the best quantitative results for PSD and DSD in WBM and OBM/SBM systems. In fact, in the case of OBM/SBM DSD monitoring, optical microscopy appeared to be the only viable monitoring solution at present for weighted muds. It was found that the dilution required for image analysis of DSDs in OBM/SBM did not appear to affect droplet size, most likely due to absence of high-turbulence mixing and shearing during the dilution and image capturing process.
- Fine-grade LCM materials exhibit negligible degradation and appear to maintain largely stable PSDs under conditions of moderate shear. Medium-grade calcium carbonate, however, degrades readily. Contrary to earlier analyses reported in literature, we find that medium-sized graphite also suffers from shear degradation, to almost the same degree as calcium carbonate. These results are relevant to wellbore strengthening in particular, where maintaining an optimum PSD is crucial to maximize strengthening benefits. Therefore, LCM degradation should be monitored, preferably in real-time with automated equipment, and managed with appropriate maintenance procedures (which should be automated also).
- Our study provides an in-depth look into the behavior of OBM/SBM DSD and its dependence on OWR, emulsifier additions, shearing conditions, etc. Even though the work is preliminary, it clearly shows that real-time OBM/SBM invert emulsion quality monitoring, using suitable automated equipment, is now possible. When applied in the field, this would enable optimum fluid maintenance through chemical additions and the use of dedicated shearing units (all of which should be automated also). In turn, the operational benefits would range from improved OBM/SBM operational fluid performance to cost savings associated with optimized chemical additions.

Acknowledgments

We thank Baker Hughes for financial support of this project and the creation of the Baker Hughes Drilling Automation labs at the University of Texas at Austin. Dennis Clapper (Baker Hughes) and Dave Marshall (Baker Hughes, retired) are thanked in particular for all their assistance and guidance throughout the work. JM Canty, and in particular Tod Canty Sr. and Jr., Justin Halbach and Ricki Gomez, are thanked for use of their equipment and valuable assistance with the Canty equipment experiments. Mettler Toledo, and in particularly Anjan Pandey, Rodrigo Maciel and Carl Phillip, are thanked for the use of their equipment and assistance with the Mettler Toledo equipment experiments. We thank Fred Growcock with Oxy for valuable advice, and Oguz Incedalip and Greg Sullivan for their help in the experiments at UT Austin.

Nomenclature

DSD = Droplet Size Distribution
ES = Electrical Stability
FBRM = Focused Beam Reflectance Measurement
LCM = Lost Circulation Material
MT = Mettler Toledo
OBM = Oil Based Mud
OWR = Oil Water Ratio
PSA = Particle Size Analyzer
PSD = Particle Size Distribution
SBM = Synthetic Based Mud
WBM = Water-Based Mud
ZP = Zeta Potential

References

Al-Mutairi, S. H., Nasr-El-Din, H. A., & Hill, A. D. (2009, January 1). Droplet Size Analysis of Emulsified Acid. Society of Petroleum Engineers. doi:10.2118/126155-MS

Allen, Terence. 1996. Particle Size Measurement: Volume 1: Powder Sampling and Particle Size Measurement. Particle Technology Series. Springer Netherlands. https://books.google.com/books?id=5rBP5OFdrvkC.

Evans, N.(2000). High Performance Emulsifiers for Synthetic Based Muds. SPE Annual Technical Conference and Exhibition. Dallas, Texas.

Growcock, F. B., Ellis, C. F., Schmidt, D. D., & Azar, J. J. (1994, March 1). Electrical Stability, Emulsion Stability, and Wettability of Invert Oil-Based Muds. Society of Petroleum Engineers. doi:10.2118/20435-PA.

Kumar, A., Chellappah, K., Aston, M., & Bulgachev, R. (2013, June 5). Quality Control of Particle Size Distributions. Society of Petroleum Engineers. doi:10.2118/165150-MS.

Morrison, I.D. and Ross, S. Emulsions: Colloidal Dispersions: Suspensions, Emulsions and Foams, John Wiley & Sons Ltd, NY USA (2002).

Ronaes, Egil, Truls Hosy Fossdal, and Tore Stock. 2012. “Real-Time Drilling Fluid Monitoring and Analysis - Adding to Integrated Drilling Operations.” In IADC/SPE Driling Conference and Exhibition. San Diego, California: Society of Petroleum Engineers. doi:10.2118/151459-MS.

Scott, Paul Daniel, David Hale Beardmore, Zack Lee Wade, Eddie Evans, and Krista Deanne Franks. 2012. “Size Degradation of Granular Lost Circulation Materials.” In IADC/SPE Drilling Conference and Exhibition. Society of Petroleum Engineers. doi:10.2118/151227-MS.

Sjoblom, J. (2001).Encyclopedia Handbook of Emulsion Technology. Marcel Dekker Inc. New York, New York.

van Oort, E., Hoxha, B., Yang, L., Hale, A.H., "Automated Drilling Fluid Analysis using Advanced Particle Size Analyzers", paper SPE-178877, IADC/SPE Drilling Conference and Exhibition held 1 – 3 March 2016 in Fort Worth, TX, USA.

Young, S., De Stefano, G., & Lee, J. (2012, January 1). Advances in Invert Emulsion Performance Through Novel Emulsifier Chemistry. Society of Petroleum Engineers. doi:10.2118/153770-MS.