application note

Particle size analysis of drilling muds and their components

Introduction

Control of the physical properties of drilling mud systems is important in enabling the development of new oil wells and maintaining oil well operation. Initially muds were used to cool and lubricate the drill bit, and remove debris from the drill well. Control of the rheological properties and density of the mud system ensured debris removal could be achieved whilst also controlling the hydrostatic pressure in the well. However, from the 1930's onwards, it became clear that if the solids particle size within the mud system was carefully regulated relative to the pore size within the geological formation being drilled, muds could also help maintain well stability and prevent formation damage through fluid invasion into permeable rocks. This is particularly true when drilling shales, where fluid invasion not only threatens well stability, but also causes significant pressure losses during well operation. Here, selection of the correct mud system can significantly improve shale inhibition.

The engineering of different muds for drilling operations requires access to routine particle size analysis capabilities. The Malvern Mastersizer 2000 laser diffraction system enables users to rapidly and reproducibly measure the size of different mud components. In combination with other physical property measurements, such as rheological and density measurements, the system can enable the development of high performance water and oil-based drilling muds, allowing the mud characteristics to be matched with the nature of the formation being drilled. This can be a significant aid in the pre-planning phase of well operation as well as during production.

This application note describes the principles associated with drilling mud characterization and introduces the use of the Mastersizer 2000 for the measurement of mud samples.

Drilling Mud Functionality

Modern drilling mud systems are designed to enable oil extraction from different geological formations by ensuring that oil well stability is maintained whilst enabling the extraction of oil from the production zone. The mud is designed to:

- Prevent the flow of oil and gas while drilling. This is achieved by altering the density of the mud so that the hydrostatic pressure in the well is balanced.
- Lubricate and cool the drill string during operation
- Provide a means of well cleaning and the transport of cuttings from the production zone whilst preventing rock dispersion, as this could block the formation.
- Stabilize the drill well and avoid damage to the production zone during drilling operations.
- Prevent fluid and solid invasion into the formation

Control of the particle size and concentration of the particulates in the mud is critical in developing a mud system which yields good well stability and prevents fluid invasion. Ideally, the mud particle size should be small enough to bridge across the pores within the formation being drilled, thus forming a "filter cake" which prevents the drill solids and other mud components, (e.g. polymers) from entering the formation. This helps to avoid fluid loss, maintains the well pressure and can stabilize shale-based formations. However, the mud particle size must also be large enough to ensure in-depth penetration of the mud into the pore structures does not occur, as this would itself lead to formation damage via pore blockage.

Choosing a mud particle size

In the past, much research has been dedicated to understanding how to match the particle size of the drilling mud to the type of rock being drilled in order to prevent invasion of solids into the formation and a resulting reduction in permeability. Abrams[1] proposed that the median particle size (Dv50) of the bridging additive should be equal to or slightly greater than one third of the median pore size of the rock so as to prevent pore blockage. Similarly, Hands[2] proposed that the Dv90 (the particle size below which 90% of the volume of material is found) should be equal to the pore size in order to limit mud penetration into the pore structure. However, it has recently been determined that damage can result from the invasion any polymers present in the mud into the formation, along with any fine particulates formed during drilling process. It is therefore important that the filter cake produced by the mud is capable of filtering out these fine particles. This requires the packing of the particles within the filter cake to be controlled, something which is related to the width of the mud particle size distribution as well as the median particle size.

Drilling mud formulations

Drilling muds can either be formulated as water-based or oil based systems. Water-based muds are considered to be more environmentally friendly and are relatively inexpensive to produce. However, they can be technically challenging to formulate and more costly to maintain, as the presence of salts and other additives can have a large effect on the mud particle size distribution. Oil-based muds, on the other hand, are generally easier to formulate and maintain. However, they do represent a possible pollution risk and are more expensive to produce.

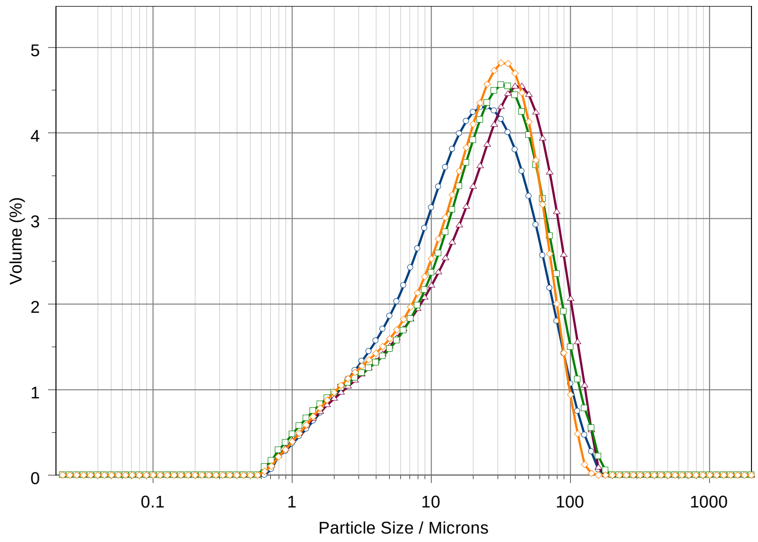

Figure 1: 4 Barite samples obtained from different producers.

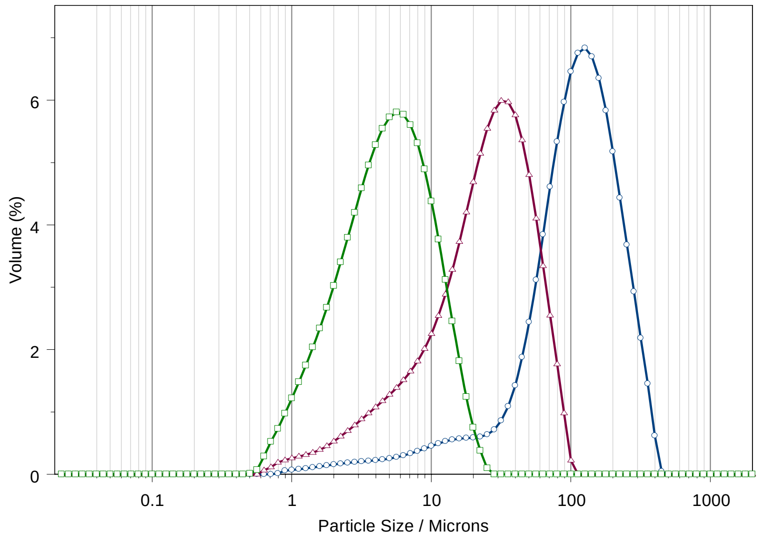

Figure 2: Particle size distributions for coarse, medium and ultra-fine calcium carbonate grades.

Each mud system will contain the following components:

- A mineral which controls the weight of the mud.
- A bridging solid.
- Wetting and thickening agents.
- Salts, which are added to aid with shale inhibition. The salt is contained in aqueous emulsion droplets within oil-based muds.

In the case of water-based muds, other additives such as starches and polymers are added in order to reduce fluid loss. Clays, such as Bentonites, may also be used to control the mud rheology.

Measuring the size of drilling mud components

Barite

Barite is commonly used as a weighting agent within both aqueous and non-aqueous drilling mud systems. Control of the particle size is important as the presence of coarse particles may lead to settling out, causing equipment damage, whereas fines may yield inadequate weighting and problems with formation damage. The American Petroleum Institute (API) specifies that the grinding of barite should achieve a size distribution where the percentage of material above 75 microns is minimized whilst ensuring that the percentage of material below 6 microns in size is no higher than 30% by weight. Figure 1 shows the particle size distributions for barite samples produced by different suppliers. It is reasonable to assume that barite has been manufactured to perform the same task in each case, in line with the API's specifications. For this reason the size distributions are broadly similar, particularly in respect to the fines content.

Calcium Carbonate

Calcium carbonate can be used in drilling muds not only as a weighting agent but also as a bridging material. It is often used in preference to barite because it is acid-soluble and can therefore be easily dissolved as part of the process of cleaning up the production zone. The particle size must be controlled in order to ensure that bridging is achieved and to provide adequate weighting. This requires the particle size to be chosen relative to the properties of the formation being drilled. Different grades of calcium carbonate are therefore available (figure 2), ranging from coarse (> 100 microns Dv50) to ultra-fine (< 10 microns Dv50).

Selecting Mud Measurement Conditions

Although the measurement of mud systems is relatively straightforward using laser diffraction, it is important to ensure the dispersion conditions used during any measurements are controlled. Laser diffraction measurements require significant dilutions to be carried out in order to reach the optical concentrations needed to yield realistic results. If the process of dilution is not controlled, inaccurate results can obtained. For example, Sharma *et al* [3] showed that the particle size reported for Bentonite is completely different when measured using water as a dispersant compared to when it is measured using isopropyl alcohol (IPA). This can be confirmed using the Mastersizer 2000 (figure 3), with a 40 micron shift in the reported Dv50 being observed when moving from IPA to water. In both cases the maximum degree of dispersion has been achieved. In order to understand which result is indicative of mud performance, the dispersion conditions within the mud system during use must be considered.

In general, when measuring water based muds, the ionic strength of the dispersant used in the laser diffraction measurement should be adjusted to ensure it is the same as in the mud system. This will ensure that the state of dispersion of the mud is maintained during dilution, as well as guarding against the dissolution of any salt-based compounds. For oil based muds, the viscosity and surface tension of the dispersant are important considerations.

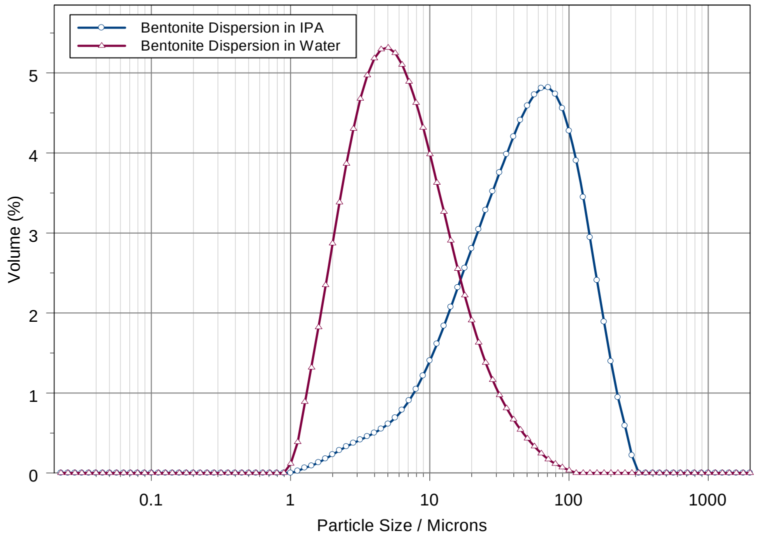

Figure 3: Comparison of the state of dispersion achieved for Bentonite prepared in IPA and in water.

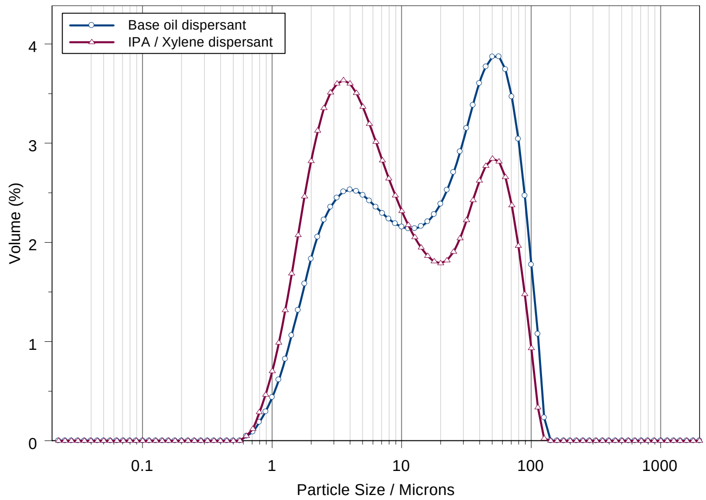

Figure 4: Change in particle size observed for an oil based mud measured in an IPA/Xylene mixture and in base oil.

An example of the importance of correct dispersant choice is shown in figure 4. Here, the particle size of an oil based mud has been measured. Initially the measurements where carried using a mixture of IPA and Xylene as a dispersant, yielding a relatively fine particle size. However, this result did not correlate well with rheological measurements – such a fine particle size would be expected to yield a high viscosity whereas in reality the viscosity was relatively low. Investigation of the state of dispersion of the mud system showed that dilution using the IPA/Xylene mixture caused dilution shock, resulting in a significant change in the particle size. The particle sizing method was therefore changed so that the base oil present in the mud was used as the dispersant. This yielded a larger particle size, correlating with the rheological observations.

Summary

Measurement of the particle size of drilling muds is an important aspect of oil well operation, enabling the properties of the mud to be matched against the geology present at the well site. Laser diffraction provides a rapid, reproducible method of particle size determination for both water and oil-based mud systems, allowing the properties of the mud to be routinely checked during the planning phase of well operation as well as during production. However, as with any other sizing method, the method of mud dispersion must be controlled if realistic measurements are to be made.

References

[1] Abrams; “Mud Design to Minimize Impairment Due to Particle Invasion.”; JPT (May 1977), 586.

[2] Hans *et al*.; “Drill-in Fluid Reduces Formation Damage, Increases Production Rates.”, Oil and Gas Journal (July 1998), 13.

[3] Sharma *et al*; “Strategies for Sizing Particles in Drilling and Completion Fluid.”, SPE Journal (March 2004), 13.

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