The influence of particle type and size distribution on viscosity in a non-Newtonian drilling fluid

Tor H. Omland[1], Bjørn Dahl[1], Arild Saasen[1], Kåre Svanes[1] and Per A. Amundsen[2]

[1-]Statoil, NO-4035 Stavanger Norway.
[2-]University of Stavanger, NO-4036 Stavanger, Norway

ABSTRACT

When drilling an oil well, the solid particles added to the drilling fluid system prior to or during drilling, affect the fluid's viscosity. It is commonly assumed that the most significant contribution to fluid viscosity comes from so-called low gravity solids. It is also believed that the viscosity is directly dependent on the number of particles in the system and the particle size distribution (PSD). The current paper presents experiments performed to differentiate between different solid particles in the fluid system and study the effects of particle size distribution on viscosity. We also present hydraulic simulations which show how the different solid contaminants can affect the drilling process.

INTRODUCTION

When drilling oil wells, excessive drilling fluid viscosity can lead to various operational problems like improper hole cleaning, stuck pipe, lost circulation due to fracturing the formation etc. It is commonly assumed within the industry that the so-called low gravity solids (LGS) affect the drilling fluid performance negatively by giving a significant contribution to fluid viscosity. LGS is a general term for drilled formation particles with a specific gravity of 2.2-2.8 SG which are released from the formation and incorporated into the fluid system. The upper set limit for the amount of LGS is therefore typically set to 200 kg/m^3, but is not differentiating between the type of formation drilled or the particle size distribution.

In the present study we shall attempt to validate these assumptions experimentally. The laboratory testing conducted includes using various types of solid particles of different size distributions and investigation of their effect on the fluid viscosity. The experiments also include rotational viscosity measurements as well as measurements of the viscoelastic properties of the different fluids.

In order to quantify the effect on drilling performance, we have also performed hydraulic simulations of pump pressure and equivalent circulating density (ECD), i.e. an expression for the sum of annular friction pressure loss and fluid density, using the parameters retrieved from our laboratory experiments.

FLUID PROPERTIES AND TESTING PROCEDURES

The fluids tested consist of a standard fluid composition with different types of particles added. To validate the effects from of particle types, various clays and sand were tested as contaminants. This was done to simulate different types of drilled solids which one can experience during the drilling process. Additionally, samples were collected offshore from silty formations and tested as a contaminant in order to provide as realistic parameters as possible.

The fluids were mixed according to standard procedures by shearing the samples using a Silverson shearing unit. After the shearing of the base sample, additions of the different solid particles were made. Table 1 shows the composition of the reference fluid.

Table 1 The composition of the reference oil based drilling fluid

Component	Concentration (/liter)
Base Oil (ml)	538
Org. Clay (g)	13.5
Emulsifier (ml)	20
Wetting Agent (ml)	8
Lime (g)	7
$CaCl_2$ (g)	45
Water (ml)	187
Barite (g)	854

To this fluid, 400 kg/m^3 of different solid particles were added, using a Hamilton Beach mixer.

The size distribution of the particles added in sample 2 to 4 is given in figure 1. This size distribution was chosen because it has been observed that a large admixture of fine grinded material increases the viscosity, independently of the particle type.

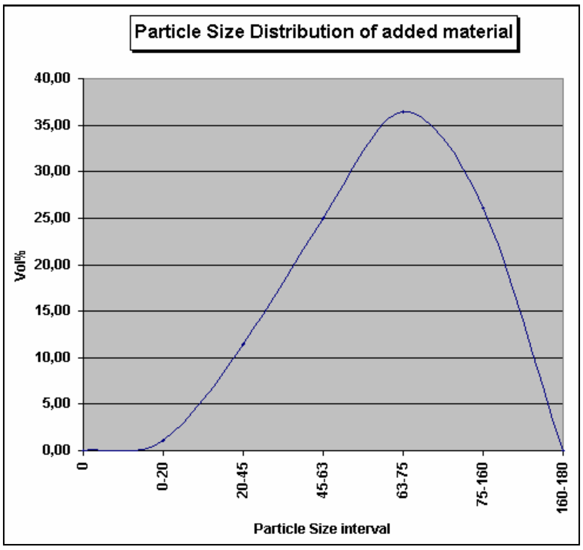

Figure 1 Particle Size Distribution of particles added for sample 2-4

For sample no.5, sand particles with a size in the range of 63-75 µm were used. Sample no.6 consisted of a continuous distribution of particles smaller than 160 µm in size from silty formations. Table 2 shows an overview and description of the various contaminants tested.

Table 2 Description of the different samples and their contaminants (400 kg/m^3 added)

Sample Description	Contaminant Description
Reference fluid	-
Wyoming Bentonite	Swelling Clay
Foss Eikeland Clay	Dispersive Clay
Sand (PSD-figure 1)	Sand
Sand: 63-75 microns	Sand
Drilled formation	Silty Shale

As can be observed from figure 2, the variations in viscosity are significant depending on particle type. When contaminating the samples with sand, a smaller increase in viscosity was observed.

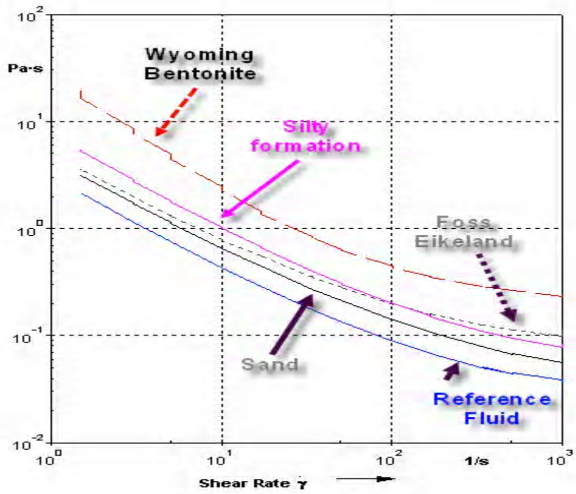

Figure 2 Viscosity of the different samples depending on their contaminant

The effect when adding the clays and the particles retrieved offshore, were more significant. This shows that not only the amount of particles in the system, but also the type of formation drilled affects the drilling performance.

PARTICLE SIZE DISTRIBUTION'S AND SHAPE'S EFFECT ON FLUID VISCOSITY

The effect on viscosity by addition of larger amounts of solids (concentrations above 50 % by volume), has been quantified by Farris[1]. Figure 3 shows how optimisation of a tertiary mixture of solids can be made to minimise the viscosity increase by providing an optimum particle size distribution in the mixture.

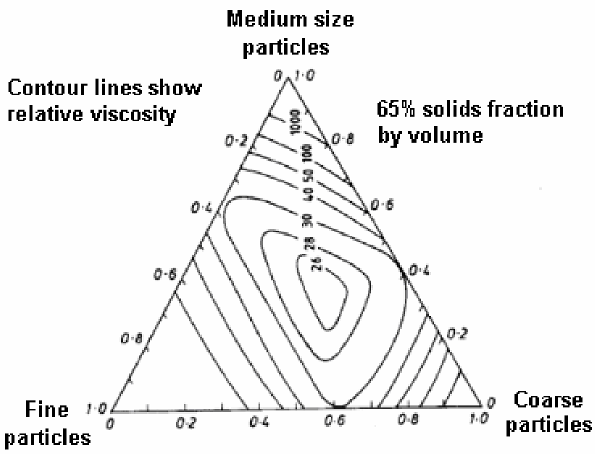

Figure 3 The effect of particle-size distribution on trimodal suspension viscosity (shown for 65 % solids)

Our laboratory experiments show that the viscosity of the fluid with added particles in the range 63-75 μm is higher than the one with particles having a continuous size distribution. This can be masking effect from already having sized barite particles in the system. Unfortunately, the cut of the 63-75 μm addition is not exact which can also contribute to the observed effect. The results given in figure 4 show the differences between the two differently sized (63-75 μm) sand fractions and the reference sample with no additional particles added.

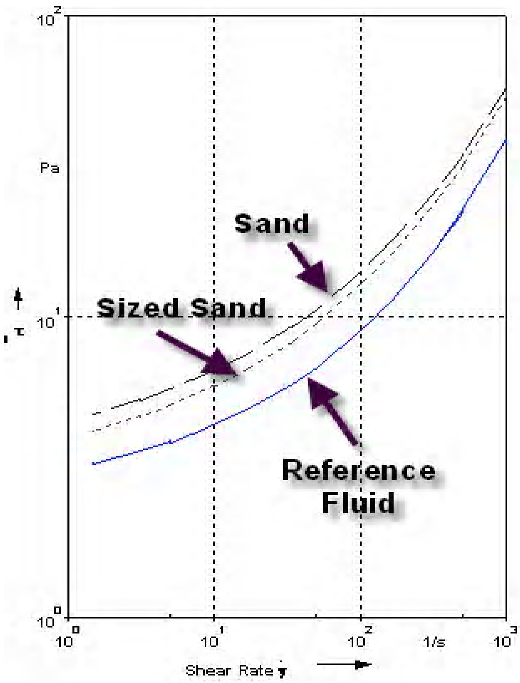

Figure 4 Shear stress of distributed sand particles vs. narrower sized distribution compared to the reference sample

Effect of particle shape on viscosity

The particle shape will also influence the viscosity. A number of studies have shown that any deviation from a spherical shape of the particles will increase the viscosity. A study performed by Clarke[2] shows the dependency of particle's aspect ratio (length vs. width). From figure 5 it can be observed that lower aspect ratios provide less viscous fluids. Our experiments corroborate these results: High aspect ratio clays give significantly higher viscosity than the rounded sand particles.

Barnes[3] showed empirically that for disc-shaped material as clay, the intrinsic viscosity [η] is expressed as:

$$[\eta] = \frac{3 \cdot (axialratio)}{10} \qquad (1)$$

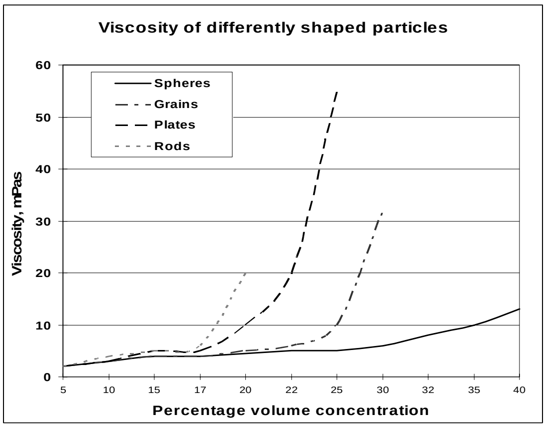

Figure 5 Dependence of the viscosity of differently shaped particles in water on concentration at a shear rate of $300s^{-1}$

VISCOSITY INFLUENCE ON WELL HYDARULICS

The fluid viscosity will influence the drilling process by increasing the ECD. We simulated the performance on a field case using special hydraulic simulation software. Figure 6 shows the results from these simulations with input on viscosity from the experiments.

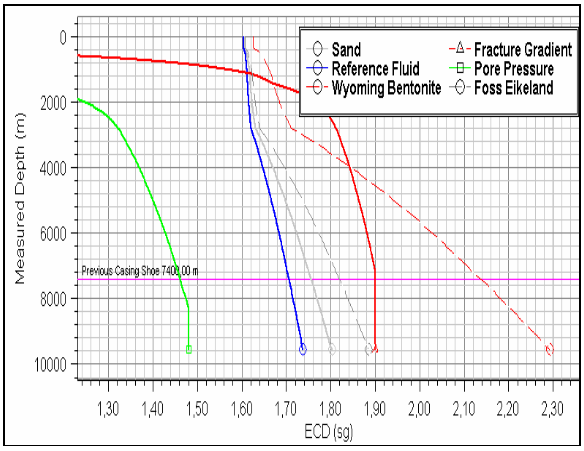

Figure 6 Simulated ECD for example well

The results show that the fluid composition used will be able to tolerate significant amounts of sand as a contaminant, but is greatly affected by drilled solids in the form of highly swelling clays. The simulations show that by incorporation of 400 kg/m^3 of Wyoming bentonite into the fluid system, the well would not have been able to be drilled. The sand contamination would on the other hand still make this well possible to drill with the set well design.

CONCLUSIONS

The laboratory study performed shows that the amount of low gravity solids that a fluid system can tolerate is strongly dependent on the formation drilled. If drilling a formation consisting of low-reactive sand, minor increase in viscosity will be observed. For highly reactive clay formations, on the other hand, the viscosity increase can be dramatic even at lower concentrations and can be quite detrimental to the drilling performance.

REFERENCES

1. Farris, R.J., “Prediction of the Viscosity of Multimodal Suspensions from Unimodal Viscosity Data”, Trans. Rheological Soc. vol 12 pp. 281-301, 1968

2. Barnes, H.A., Hutton, J.F., and Walters, K. (1989), "An Introduction to Rheology", Elsevier, Amsterdam, pp. 115-139.

3. Barnes, H.A, “Dispersion rheology: 1980”, Royal Soc. Of Chem., Industrial Division, London