Experimental Analysis of Yield Stress in High Solids Concentration Sand Slurries used in Temporary Well Abandonnement Operations

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ABSTRACT

For temporary abandonment of high pressure and high temperature (HTHP) oil well reservoir sections it is occasionally practical to fill the reservoir with a high solids concentration material instead of cementing this section back. These sand slurries will typically have a particle concentration around 70-80% by volume. Such slurries will experience a very high yield stress, and pump friction is dominated by this yield stress. The current paper presents an experimental study where the yield stress of such slurries is minimized by using a proper particle size distribution.

INTRODUCTION

Occasionally, when drilling offshore wells it is necessary to temporary plug back wells. A common need for a temporary plug back is that the wells have to be drilled with one rig and the completion operation must be done with a different rig. A reason for such a situation is that the completion equipment may not yet be ready for implementation in the wells when the wells have to be drilled for exploration or appraisal purposes.

Historically, the common method to plug back wells in the temporary time periods while waiting for the completion rig, has been to partially cement back the open hole section. In this case, the completion rig must re-drill this cemented section.

A system that allows a temporary plug back of a reservoir section without the need to re-drill that section has been developed[5]. This system consists of a concentrated sand made into a slurry with water and brines. The sand slurry has a particle fraction in excess of 70% by volume. As will be described, the particle size distribution controls the rheology, permeability and porosity of the slurry[1,2].

SAND SLURRY

Farris[2] quantified the effects of controlling viscosity by adding solids in large fractions. He quantified the relative viscosity of a selection of particle slurries which were composed of selected monodisperse particles. In a mixture consisting of two monodisperse particle sizes, where the larger particles being five times as large as the smaller, the minimum relative viscosity was found at a blend with approximately 60% being the larger. It is therefore possible to increase the particle volume concentration from 60% to far above 75% without changing the viscosity just by changing from a monodisperse particle suspension to a bimodal suspension as described above.

An even better improvement than obtained for the pumpability of bimodal suspension can be obtained for more complex compositions as illustrated in Figure 1. In this figure it is shown contour lines for the relative viscosity values for threemodal suspensions. This data selection illustrates the same effects as described in the previous paragraph. The viscosity of multimodal suspensions will have a minimum for a relatively high concentration of the larger particles. The presence of too much fines will create a high viscosity.

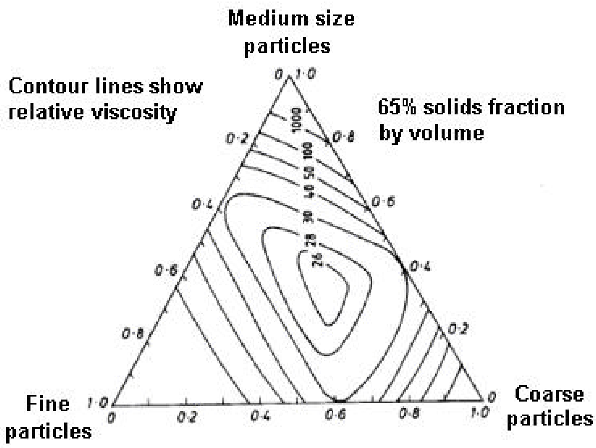

Figure 1. The relative viscosity of a particle suspension based on three different particle sizes for a total particle concentration equal to 65% (based on the work by Farris[2,3])

YIELD STRESS SLURRIES

Slurries with such high concentration of solid particles as used in case can be treated as having a yield stress, independent if a yield stress really exists[4,6]. Typical yield stresses for this kinds of materials can be in the range of 100-300 Pa. In the practical operations with this type of material, both in a test well and when applied to a Kristin oilfield well[7], the yield stress has been anticipated to be in that range possibly as high as 330 Pa. During flow of such materials it is also likely that wall slip is occurring to a greater extent. This is expected to have happened in the practical pumping operations.

SLURRY COMPOSITION

The investigated slurries consist of a mixture of a sand, anortosite fines from the waste line in ilmenite production and microsilica. The sand is a natural moraine sand predominantly quartzitic lenticular grain shapes, which was washed and sorted to eliminate humus and particles larger than 2.5 mm. The maximum size represents the practical limitation given by pumps, valves and fittings used in the placement process into oil wells. The anortosite fines is a waste rock after crushed ilmenite carrying rock has gone through a flotation process to extract the valuable ilmenite. The particles, primarily anortosite and feldspar, are angular in shape and range in size from 1 mm to a few microns. The microsilica is silica particles from the fume from ferro-silicium plants. These particles are spherical and have a mean particle diameter between 0.5 and 1 micron.

The sources of particles are blended in portions such that the aggregate of particles covers the full spectrum of grain sizes from 2.5 mm to sub-micron, approximately following the equation proposed by Andreassen[1]

$$(1-R)=\left(\frac{d}{D}\right)^{q} \qquad (1)$$

where $(1 - R)$ is the fraction pass through a screen with the opening size d. The factor D is the maximum grain size and q is the Andreassen exponent which is in the range 0.25 to 0.37.

The particle aggregate is blended with water, a polycarboxylic polymer dispersant and an aliphatic alcohol polymer added to viscosify the water phase. In addition to these constituents, sodium formate and monoethylene glycol were added in different concentrations to exhibit proper control on the freezing point of the mixture.

LABORATORY TESTING

Various tests have been done to identify changes in the yield stress when changing the concentrations of single components. In the following paragraphs and figures three series of tests with different sand mixtures are shown. Every test result reported in the figures are averages of two measurements.

In the first series of tests sand was replaced by anortosite fines in steps and the yield stress was measured for every change. A second series of tests were performed where sand was replaced by silica fume to see how yield stress developed in this case.

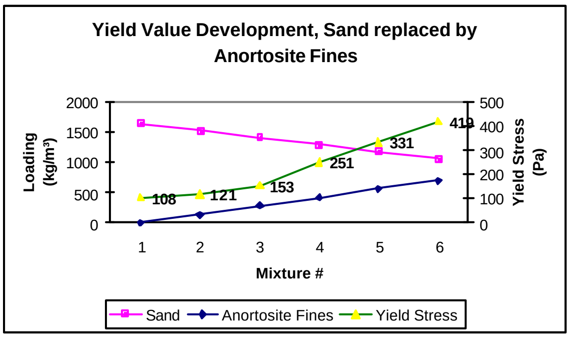

Figure 2. The yield stress development when sand is replaced by anortosite fines in slurries with 29.3% by volume water.

The majority of the tests were concentrated on understanding the replacement of sand with anortosite fines. This selection of experimantal conditions were selected because it is the combination of sand and anortosite fines that will be the primary control of the permeability of the mass if the water is seeping out. As can be seen from Figure 2, the yield stress increases with increasing anortosite fines. This result seems to contradict the conclusion obtained by Farris[2] as indicated in Figure 1. In the present results the minimum yield stress was found in absence of anortosite fines.

It was anticipated that the minimum viscosity would have occurred for a non-zero anortosite fines concentration. The measurements shown in Figure 2 indicates that the minimum occur for a slurry totally without anortosite fines. This minimum is most likely caused by the combination of particles defined by the sand particle size distribution and the particles from the 6.6% added silica fume.

Although, the minimum yield stress is found in absence of the anortosite fines, these fine particles are needed to maintain a stable slurry during placement. The desired mixture would be a mixture with as high anortosite fines concentration as possible, at the same time as the yield stress of that mixture remains relatively low.

Addition of water will minimize the yield stress further. If the water concentration of mixture 2 shown in Figure 2 is increased with 2.3% to 31.6%, the yield stress can be reduced to 77 Pa. This slurry, however, will not be stable and will not contain enough particles to create a low permeable matrix over the entire placement region if the water is bled off.

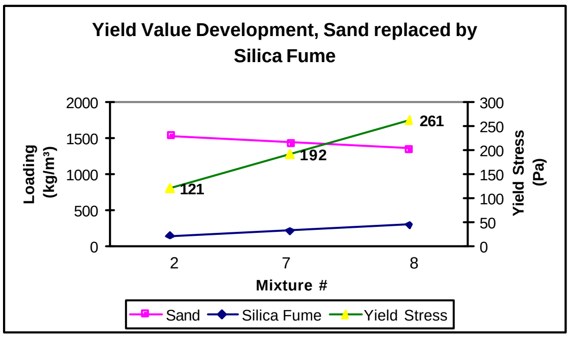

Figure 3. The yield stress development when sand is replaced by silica fume.

If silica fume is replacing sand the yield stress will increase as shown in Figure 3. Most of the particles in the silica fume are within colloidal sizes. These particles binds large amount of water and hinder the water in lubricating the flow of larger grains, resulting in an increase in the yield stress. Because of the presence of the silica fume the mixture becomes more stable and the placement of the material becomes safer. Like for the anortosite fines, it is desired to use only the necessary amount to make the slurry stable to prevent the yield stress to become too high.

Sodium formate has been used as temperature controlling agent for practical operations during winter time[7]. Sodium formate will interact with the silica fume and make the mixture yield stress high by coagulating the fume particles with other particles. Therefore, to make a mixture with lower yield stresses for future winter operatins, the sodium formate was replaced by monoethylene glycol. As shown in Figure 4, the monoethylene glycol was indeed a better alternative with respect to obtaining a low yield stress than sodium formate. Monoethylene glycol is also known to have lubricating properties on pipe movements.

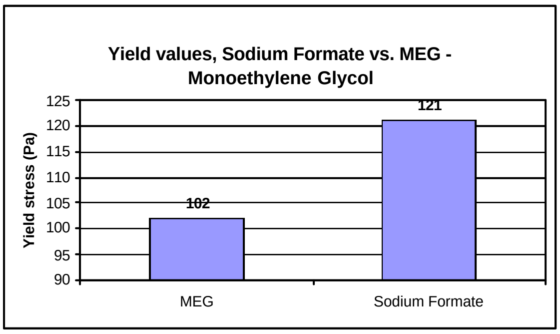

Figure 3. The yield stress difference when monoethylene glycol was used instead of sodium formate as temperature controlling additive.

CONCLUSION

For sand slurries with a particle volume concentration above 70%, a series of experiments has shown that the yield stress can be controlled by adjusting the particle size distribution.

In a field application the yield stress is anticipated to have been in the excess of 300 Pa. The current experiments showed that the yield stress can be reduced to less than half of the value that was used in the field application. Still the slurries remain stable with a low permeability matrix after any bleeding off of water.

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