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Effects of Shear History on the Viscosity and Gel Development of Oil Well Cement Slurries.

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ABSTRACT

Two types of propeller blades for high speed mixing of cement slurries are in use in laboratories for testing of oil well cement. These blades are anticipated to give approximately equal impact on test results. However, the present study show that the different input of mixing energy from these blades does have an impact on the viscosity measured at high shear rates. The different amounts of mixing energy also influence the gel development of the slurries.

INTRODUCTION

In primary oil-well cementing a slurry is mixed on the rig before it is pumped down and placed at the cementing interval between the casing and the formation. Oil-well cementing is one of the most important operation performed on a well. Without complete zonal isolation the well will never reach its full potential as a gas or oil producer. The success of a cementing job demands maximum control of the cement slurry properties and the basis for these propeties are extensive tests carried out in the laboratories.

The cement laboratories follow standard mixing and testing procedures given by API[1] . The standard mixing procedure in the laboratory involves the use of a high speed mixer. However, the dimensions of the propeller type mixer blade is not given. Two different types of propeller blades seem to be commonly used in laboratories located in Scandinavia. One is a propeller blade made of hard metal having shorter wings compared to that of the other being the original Warring Blendor propeller.

According to Laboglass[2] both types of blades are in use during testing, however the original Warring Blendor blades are most frequently used.

EXPERIMENTAL CONDITIONS

Sample preparation

In our experiments a Norcem Class G oil well cement was used. All samples were mixed using cement and distilled water with a w/c-ratio of 0.38 by weight. No other additives were used. This W/C-ratio gives a slurry readily mixable,[3] combined with a low tendency to develop free water in the slurry. The volume of each test sample was 600 ml. All tests were carried out at 20 ± 2 °C.

All the samples were mixed in accordance with API Spec.10.[1] For the initial high speed mixing a propeller- type mixer is to be used. This mixing consist of an initial period of 15 seconds with mixing at 4000 rpm. while adding cement to water, then the speed is increased to 12000 rpm. for an additional 35 seconds.

For high speed mixing we have used a Warring Blendor and two different types of propeller blades: a hard metal propeller blade, a HM-blade, and the original Warring Blendor propeller blade, a WB-blade.

After the high speed mixing the sample is placed in an Atmospheric Consistometer and is mixed at 150 rpm. for 20 minutes prior to any measurements.

Mixing energy

The input of mixing energy was measured by use of a power meter. Only the power consumption during the 35 seconds with mixing at 12000 rpm. was measured. This is in accordance with measuring methods used by Orban et al.[4] who measured the input of mixing energy for different types of cement slurries. The power consumption is given as an average reading during this period. The power consumption with an empty mixing container was measured and subtracted from the final reading thus giving the net input of mixing energy.

Viscosity measurements

Measurements were done by use of a Baroid Multi-Speed Rheometer and in accordance with API.[1] This is a rotational concentric viscometer. The standard shear rates used were: 5.1, 10.2, 17, 34, 51.1, 102, 170, 340, and 511 s^{-1}. Gel strength was measured as the peak shear stress at a shear rate of $5.1 s^{-1}$ after 10 seconds and 10 minutes static delay.

RESULTS

Mixing energy.

The measured input of mixing energy from the experiments using the two different types of propeller blades is shown in Table 1. The value of 5.6 kJ/kg obtained when using the WB-blade is similar to the value reported by Orban et. al.[4] .The mixing energy obtained when using the HM-blade is significantly less; being approximately 70 per cent of the WB-blade mixing energy.

Table 1. Measured input of mixing energies from different propeller blades using a neat slurry with w/c-ratio of 0.38.

Propeller type \ Cement slurry	Class G
Hard metal propeller blade	3.9 kJ/kg
Warring Blendor propeller blade	5.6 kJ/kg

Viscosity measurements.

In Fig. 1 the measured shear stress is given as a function of shear rate. Each curve represents data obtained by using the two different types of propeller blades when mixing is done in accordance with API. [1]

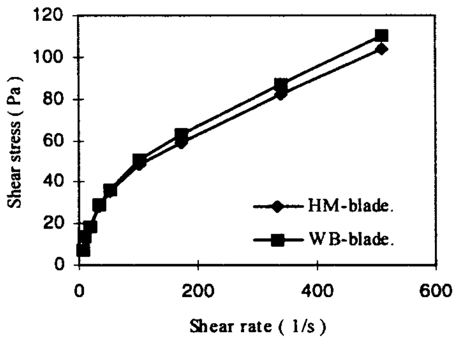

Figure 1. Measured values of shear stress as a function of shear rate by using two different types of propeller blades

For low shear rates no difference in shear stress was measured. For higher shear rates the shear stress obtained from the slurries differ. At a shear rate of $511 s^{-1}$ the slurry mixed with the WB-blade gives a 6 per cent higher reading of shear stress.

The gel strength of the slurries have been measured as a function of time spent in the Consistometer. Results are shown in Fig. 2.

The data obtained after 20 min. in the Consistometer represents the standard API[1] test. The WB-blade mixed slurry, being the most viscous of the two, also forms a stronger gel both after 10 seconds and 10 minutes independent of time spent in the Consistometer. The rate of static gel strength formation, i.e. from 10 seconds to 10 minutes is also higher for the slurry mixed with the WB-blade.

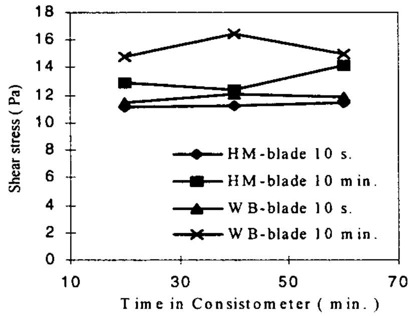

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Figure 2. Gel strength measured as a function of time in Consistometer.

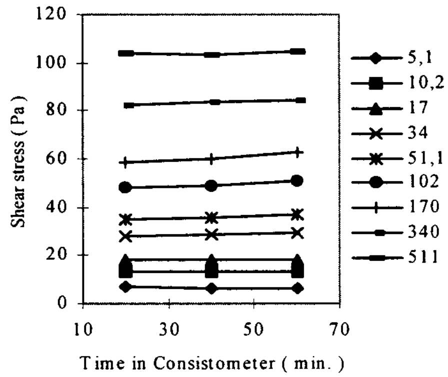

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Figure 3. Shear stress as a function of time in Consistometer when using a HM-blade for high speed mixing. Each curve represents a shear rate (s^{-1}) as given in the legend.

The shear stresses of the slurries as a function of time spent in the Consistometer are shown in Fig. 3 and 4. Each curve represents a shear rate. Again, there is a difference in shear stress between the slurries measured at high shear rates, the slurry mixed with the WB-blade showing the highest values. Both slurries show a local minima after 40 minutes in the Consistometer.

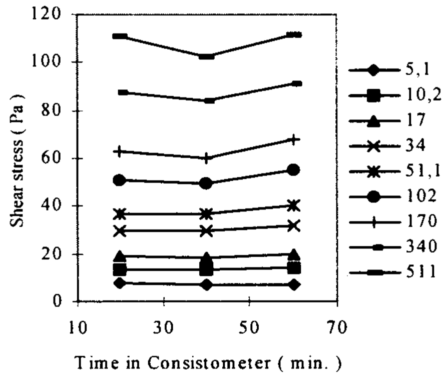

Figure 4. Shear stress as a function of time in Consistometer when using a WB-blade for high speed mixing. Each curve represents a shear rate (s^{-1}) as given in the legend.

DISCUSION

When relating input of mixing energy from Table 1 to the measured values of shear stress and gel strength in Fig. 1, 2, 3 and 4 we find that the type of propeller blade used has a marked influence. The higher energy input from the WB-blade result in a higher reading of shear stress at high shear rates and higher value of gel strength. This is still true when measuring after 40 and 60 minutes of agitation in the Consistometer.

In Fig 3 and 4 it is shown a relatively lower shear stress for higher shear rates after 40 minutes of preconditioning in the Consitometer. This local minima is more profound in the results shown in Fig 4 when using a WB-blade and thus when using a higher input of mixing energy. The local minima is in accordance results obtained by Hodne et. al.[5] and it is also in accordance with obsevations by Banfill and Kitching[6] The latter refer to it as a structural breakdown. Vlachou et al.[7,8] also measured a local minima for a retarded Class G slurry with a w/c ratio of 0.44 after 8 hours mixing in a Consistometer.

It has also been observed that at these minima the slurries, being left static, show a higher tendency of bleeding.[6]

The measured mixing energy of 5.6 kJ/kg when using a WB-blade is in close agreement with the SME (Standard Mixing Energy) of 5.5 kJ/kg introduced by Orban et. al.[4] for high speed mixing of a neat Class G slurry.

The HM-blade is similar in shape to the WB-blade, the main difference being that the four wings of the former are of equal length and shorter compared to the latter.

The law of similarity for hydraulic machines[9] gives that when other things are being similar the energy delivered by propeller blades are related to the fifth power of the diameter.

When applying this law on the relation between the diameters of the two propeller blades, a ratio of approximately 0.6 for the mixing energy input is expected. Compared to the measured ratio of 0.7, it is evident that these propeller blades does not fully meet the requirements of similarity.

CONCLUSION

The input of mixing energy have a measurable influence on the rheological properties of oil well cement slurries.

The term SME (Standard Mixing Energy) Introduced by Orban et. al. [4] is found to be valid for a neat Class G slurry when using a Warring Blendor high speed mixer with a Warring Blendor propeller blade.

As various types of propeller blades are in use in the laboratories of the oil industry there is a need for also stating type of propeller blade used in the high speed mixing procedure. Alternatively the input of mixing energy could be stated in experimental evaluations.

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