Gel Strength Development of Oil Field Cement Slurries used in Cementing Jobs in Weak Formations

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ABSTRACT

A study of gel formation properties of cement slurries similar to those used for cementing shallow weak formations in the northern part of China has been performed. The influence of gel formation, after a period without pumping, on fracture creation in such wells is being discussed. The different use of the term "gel" within different sciences has also been commented.

INTRODUCTION

In oil field cementing jobs cement slurries are pumped down the drill string or casing and up in the annulus outside the casing to seal off the formation and to prevent fluid migration outside the casing. The oil field cements are normally fairly low viscosity thixotropic slurries that exhibit yield stresses. Placement of the cement in the annulus is normally achieved by pumping without stopping. If pumping unexpectedly stops, the slurries "gel" up. In applying the pump pressure required to break this gel the formation may be fractured. Excessive loss of cement slurries into such a fracture can result in incomplete cementing of the annulus.

A well cement slurry is one of the most tested items pumped into a well. Still it is one of the most variable items. The cement raw material differ from batch to batch dependent on their chemical and mineralogical content. Besides this each plant will have quite different burning processes for the clinker. Thus each batch of cement must be expected to be different.

The term gel which is used within the oilfield industry differs significantly from the different definitions used within polymer science technology[1]. The term gel is used to describe certain thixotropic properties. Standard oil field practice is to measure viscosity parameters on a Fann 35 viscometer or on a similar type of instrument. The gel tests are performed by shearing the sample at at a shear rate of 1022 s^{-1} for 20 s. Then the sample is allowed to gel in a 10 s static period. Then the peak shear stress during start of rotation at a shear rate of 5.11 s^{-1} is recorded as the 10 s gel strength. The same procedure is repeated with a 10 minutes static period to record the 10 minute gel strength.

GEL STRENGTH AND FRACTURING

A formula which can be used to calculate the pressure required to overcome the static gel strength and start circulation can be found from Sabins and Sutton[3] (Eq. 1):

$$p = s_{gs} \frac{4L}{d_h - d_c} \qquad (1)$$

where:

- s_{gs} = static gel strength,
- L = length of annulus
- d_h = hole diameter, and
- d_c = casing diameter.

The cement slurry density will generally be so large such that the hydrostatic pressure at any location is larger than the formation pressure. If the formation is weak the additional pressure from the gel strength can therefore be sufficient to fracture the formation. In practical pumping operation it is the difference between the formation pressure and the fracturing pressure that sets the limit for the cement slurry pump rates. High pumping rates are often preferred to obtain good displacement quality as pumping at turbulent conditions is normally beneficial.

SAMPLES AND PREPARATION

The gel formation and viscous properties of three cement slurries were studied. These cement slurries were similar to those used in cementing shallow wells in the Liaohe field. The cement compositions are shown in Table 1.

Table 1. Cement slurry compositions. All values in % by weight of cement.

Constituent:	Comp. no. 1	Comp. no. 2	Comp. no. 3
Cement	100	100	100
Water	48	47	53
Dispersant	0.4		0.8
Microspheres		4.7	
Silica flour			35

The cement was an API class G oil well cement delivered by Norcem a.s. The dispersant was a sodium based naphtalene sulphonate and the microspheres were hollow ceramic spheres with a diameter between 0.15 and 0.2 mm. The dispersant, and the microspheres and the silica flour used in this study were all delivered by BJ-Services.

The specific gravity of the different slurries was 1.85 for composition 1, 1.67 for composition 2 and 1.81 for composition 3.

Mixing of the cement slurries was performed in accordance with the API procedures[2]. First the liquid additives and water were blended in a Waring blender at low speed. Thereafter, within 20 s, the dry materials were added. Then the slurry was mixed at 12,000 rpm for 35 s in the Waring blender. Finally, the slurry was pre-conditioned in an atmospheric consistometer for 20 minutes in following API spec. 10.

The cement material is continously changing after blending with water. It is fairly stable in properties after preconditioning until initial set of the slurry. The initial set is normally not expected within the first 2.5 hours. However, to avoid preparing different measurements on a cement slurry at different times of hydration, several new batches were blended for each test in the present study.

GEL FORMATION MEASURED BY STANDARD TECHNIQUES

The viscous properties and the gel formation properties measured by standard oil field techniques[2] are shown in Table 2.

Table 2. Shear stress (Pa) versus shear rate and API gel strengs of the cement slurries, measured at a temperatore of 50°C.

Shear rate (s^{-1})	Comp. no. 1	Comp. no. 2	Comp. no. 3
1022	13	27	28
511	6.4	19.5	14
341	5.1	13	11
170	3.8	11	5.6
102	3.1	9.7	4.1
51	2.3	8.7	3.1
10.22	2.3	5.6	2.3
5.11	2.6	3.8	2.0
10 s gel	1.5	4.3	2.0
10 min. gel	6.1	4.1	7.2

It is obvious from the results shown in Table 2 that cement slurry composition no. 1 has thixotropic characteristics as the shear stress measured at 5.11 s^{-1} is larger than that measured at 10.22 s^{-1}. Furthermore, the 10 s gel strength is even less than the shear stress measured at 5.11 s^{-1}.

Cement composition no. 2 does not demonstrate any gel formation within the first 10 minutes, while composition no. 3 has a 10 minutes gel similar to that of composition no. 1, although the 10 s gel stress is equal to the stress measured at the shear rate of 5.11 s^{-1}.

GEL FORMATION MEASURED WITH A CONTROLLED STRESS RHEOMETER

The gel formation properties of the cement slurries were also measured using a concentric cylinder option on a Carri-Med CSL50 rheometer. In the chosen option the inner cylinder diameter was 46.1 mm and the outer cylinder diameter was 50 mm. The height of the inner cylinder was 30 mm. The cylinder surfaces had small grooves to entrap cement particles. Maximum shear stress set in these measurements was equal the shear stress obtained in initial measurements on the Fann 35 viscometer at a shear rate of 511 s^{-1}. The rheometer ramp up and ramp down times used in the measurements were 1 minute.

The shear stress versus shear rate curves of cement composition no. 1 in the case without a static gel period and the case with a 30 minutes static gel period prior to the measurements are shown in Fig. 1. The gel is totally broken during the ramp up time. The ramp down curves are therefore equal for the different curves in the figure. This effect was observed for the different gelling periods for compositions no. 2 and 3 as well. The rheometer data for these slurries are not shown in this article. However, important results from these measurements are discussed. Thus the crossing with the shear stress axis for the ramp up curve illustrates the gel stress and the crosses at the ramp down time illustrates the yield stress of the slurries.

At a shear rate of 51.1 s^{-1}, the shear stress measured for composition no. 1 with the Fann 35 was 40% larger than that measured at zero gel time shown in Fig. 1. A similar difference was observed for composition no. 2 where the difference was 50%. These differences demonstrate the difficulties in obtaining equal blending and preconditioning of a specific slurry. The accuracy of the 35 s mixing at 12,000 rpm on the Waring blender is especially important for the final results.

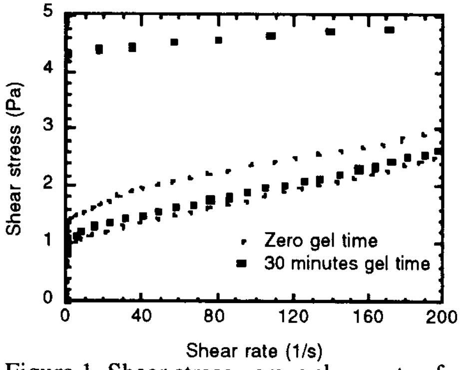

Figure 1. Shear stress versus shear rate of cement composition no. 1 without a static period and with a 30 minutes static period prior to measurements.

For cement slurry composition no. 1 there is little gel development observed for the first 5 minutes of gel time. At 10 minutes of static gelling a significant change was observed in the difference between the gel stress and the yield stress. This difference was nearly 1 Pa. When the static gelling period was 30 minutes this differnce was approximately 3.3 Pa as shown in Fig. 1. If precautions were not taken, there could be a large probability of fracturing a formation if there is a 30 minute period without pumping when using cement composition no. 1.

In the experiments with composition no. 2, a nearly instantanous gel strength formation was observed. This was about 2 Pa larger than the yield stress. This gel stress was observed for all static gel periods up to 10 minutes. However, when the shear stress did overcome the gel strength this easily formed gel was rapidely broken.

For composition no. 3 the gel stress formed at 5, 10 and 30 minutes static time was equal. However, it was more difficult to break the gel completely as the gel time increased. The gels became less fragile if the gel time incresed.

The cement composition no. 1 is somewhat similar to one of the slurries studied by Sabins and Sutton[3], They found much larger values of their gel strength after 30 minutes of static gel time. This was observed even though they used class H cement which is coarser than class G cement. However, the SG of their slurry was 1.9 which is larger than that of the presently studied slurry. An other effect is of course that they used cement from a different location and manufacturer.

CONCLUSION

A series of experiments demonstrated that cement slurries with API class G cement may have a significant gel formation. Furthermore, the study has emphasized the difficulty of measuring rheological properties of cement slurries. The different use of the term "gel" within different sciences has also been commented.

REFERENCES

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