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Geothermal well cementing: the effect of temperature and time on workability loss

H.G. Svavarsson and O.H. Wallevik
Icelandic Building Research Institute, Keldnaholti, IS-112 Reykjavik

ABSTRACT

A cement slurry is used to support the casing of geothermal wells. The slurry is pumped down the steel casing of the well and then placed in the annular space between the casing and the surrounding rock. A rheometer, developed at IBRI Rheocenter and being currently under patent evaluation, was used to measure the rheological properties of two different types of well-cementing slurries at different temperatures. Pastes with Norwegian G-cement and standard Icelandic cement were compared.

Here it is reported on the effect of temperature and time on the workability loss.

INTRODUCTION

Geothermal well cementing in Iceland is well established, with its three decades long history. Traditional Icelandic ingredients (mainly cement) has been used in addition to bentonite. Bentonite is generally composed of clay minerals, predominantly montmorillonite with minor amounts of other smectite group minerals. Bentonite swells considerably when exposed to water, making it sitable for protecting formations from invasion by drilling fluids. Under certain condition a small amount of flow loss control agent and retarder are also added to the paste. A characteristic of the Icelandic cement is its very high water-demand and yet exceptional low bleeding. This may partially be attributed to its high content of fines and silica-fume.

One of the prime role of casing cementing in geothermal wells is to anchor the casing and minimize its expansion when producing steam and to prevent buckling. At the bottom of the hole the temperature of the pressurized water may reach several hundred degrees celcius. In well cementing, Portland cement systems are routinely designed for temperatures ranging from below freezing in permafrost zones to 350°C in thermal recovery and geothermal wells. It is further designed to encounter the pressure range from near ambient in shallow wells to more than 200 MPa in deep wells[1]. Portland cement systems of normal density (~ 1.93 g/cm^3) usually exhibit low matrix permeability, if allowed to set undisturbed[2]. However, gas migration can open additional flow paths, in the form of interconnected porosity through the setting cement. The resulting set cement may suffer from an unnaturally high permeability and in the case of a geothermal well such condition would give rise to water percolation through the cement matrix. Hence, a proper understanding of cement slurry rheology is important to design, execute and evaluate a primary cementation, especially under a condition underneath the earth surface, at high pressure and high temperature. As such, the Icelandic slurry recipe with its Icelandic cement has served its purpose successfully throughout the last three decades. It has nevertheless been considered necessary to try other alternatives, such as Norwegian G-cement, which is customized to the need of oil well cementing. The thickening time is closely related to the workability loss and indicates the timespan which a cement slurry remains in a pumpable fluid state under simulated wellbore condition. The timespan may depend on temperature, pressure and the composition of the cement paste. Another important parameter, concerning well-cementing, is the time it takes to gain sufficient mechanical strength until drilling may be continued. In general, the waiting time for cement to cure is very costly in geothermal well drilling so an early strength of the hardened paster is of great importance.

EXPERIMENTAL

Two types of cement slurries were prepared. One with Icelandic cement and the other with Norwegian G-class well-cement. From now on it will simply be refered to these two slurries as the Icelandic slurry and the Norwegian slurry, respectively. The raw materials were mixed together in a Hobart blender in accordance to ASTM 305 standard. Table 1 shows the concrete recipes of the two different slurries. No polymers were used in the Icelandic slurry while ADVA Cast 530, belonging to a group of superplasticizers, was used in the Norwegian slurry. The superplasticizers serve mainly to reduce the apparent viscosity of the cement based material (i.e. of the fresh concrete, mortar and cement paste[3]).

The w/c ratio of the Norwegian slurry was adjusted at constant amount of ADVA Cast (0.06% wt. cement) and bentonite (2% wt. cement) so that its rheological behavior at room temperature (20°C) would be comparable to the Icelandic slurry.

After mixing, the rheological parameters of the slurries (τ_0 and μ) were measured in ConTec Viscometer[4] assuming a Bingham flow behavior. The Bingham plastic model is represented by the equation of apparent viscosity

$$\eta = \mu + \frac{\tau_0}{\dot{\gamma}}, \tag{1}$$

which, in terms of shear stress, is given as

$$\tau = \eta \cdot \dot{\gamma} = \tau_0 + \mu \cdot \dot{\gamma}, \tag{2}$$

where τ_0 is the minimum stress needed for the fluid to flow (yield stress). Above the yield stress, the Bingham plastic model assumes that the shear stress in linearly related to the shear rate $\dot{\gamma}$. The slope of the linear regime, μ, is called the plastic viscosity. A new type of rheometer was used to measure the flow behavior of the slurry at three different temperatures, 20, 40, and 60°C. The rheometer is currently under evaluation for patent application and will thus not be described here in details but basically it measures the torque T applied to a rotor stirring the slurry. The rotation speed is changed stepwise and the torque is measured at each distinct speed. The new type of rheometer will be called the New Rheometer, hereafter, to distinguish from the ConTec viscometer. Because of the geometrical complexity of the impeller that measure the torque, there is no simple mathematical approach to convert the measured torque and rotation speed to shear stress τ and shear rate $\dot{\gamma}$. So in the case of the New Rheometer, one has to make equation with a direct use of T as a function of N as an alternative to Eq. 1. The result may be expressed as

$$T = G + H \cdot N. \tag{3}$$

The term G is here called the flow resistance and H the viscosity but N denotes the rotation speed (rps). By comparing the values obtained by the New Rheometer to those obtained by ConTec viscometer, it has been demonstrated that the G- and H-values are proportional to the Bingham pa-

Table 1: Mixing recipes of pastes with Icelandic cement and Norwegian G-cement

Additives	**Ice.** [parts]	**Nor.** [parts]
Cement	100	100
Silica flour	40	30
Silica fume (98%)		10
Water	80	66
Wyoming Bentonite	2	2
ADVA Cast		0.06

rameters τ_0 and μ. Eq. 2 and 3 may thus be considered as being equivalent in certain sense. The rheology of the slurry was measured with the New Rheometer in a double-wall semi-sealed vessel heated with water in an open-circuit arrangement. The purpose of the semi-sealing was to prevent water removal of the slurry by evaporation at elevated temperatures. During measurement the temperature was kept constant at 20, 40 and 60°C with an accuracy of +/-1°C.

The compressive strength of the hardened paste was measured in accordance to ASTM C349-82 standard. A detailed discussion on this topic is beyond the scope of the current article so it will only be mentioned briefly here.

RESULT

The rheological parameters, obtained by ConTec Viscometer, and the compressive strength of the hardened Icelandic and Norwegian pastes are compared in Table 2. Notice that the values obtained by ConTec viscometer in Table 2 are in fundamental units while the temperature dependence of flow behavior measured in the New Rheometer are in relative units. (represented in Figs. 1 and 2).

Table 2: Rheological parameters and compressive strength at 20°C of pastes with Icelandic and Norwegian G-cement

Properties	**Ice.**	**Nor.**
Yield value [Pa]	20	23
Plastic viscosity [Pa s]	0.25	0.33
Compressive strength$_{12h}$ [MPa]	0.3	1.4
Compressive strength$_{24h}$ [MPa]	4.9	4.9
Bleeding (ISO 10426-1:2000)	$< 1\%$	$\leq 3\%$

As seen in Table 2 the 12h strength in the hardened Norwegian paste is much higher than that of the Icelandic paste whereas the 24h strength values are comparable. For oil-well cementing it is normally considered safe to carry on drilling when the strength of the concrete exceeds ~3.5 MPa. Based on the results given in Table 2 it would take 12-24h to achieve that value for both types of paste. Workability loss of the pastes at different temperatures are indicated in Figs. 1 and 2. At 20°C the flow resistance (G) and viscosity (H) of the pastes are only slightly increased in 120 minutes. At 60°C both G and H increase rapidly with time and after 90 minutes both pastes are practically rigid and impossible to pump the paste. The behavior at 40°C can be considered as being intermediate of that between 20°C and 60°C. This behavior is more obvious

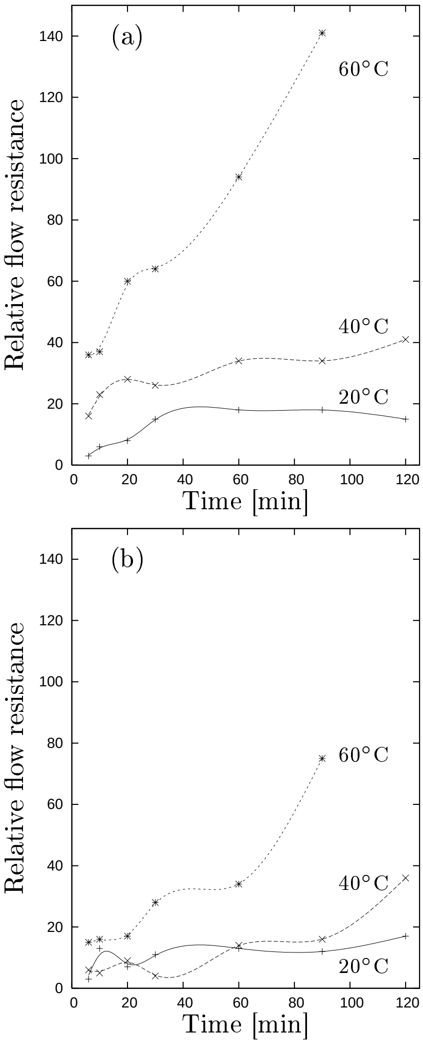

Figure 1: Flow resistance of paste measured with the New Rheometer at three different temperatures, (a) Icelandic cement of w/c=0.8 and (b) Norwegian G-well cement of w/c=0.68

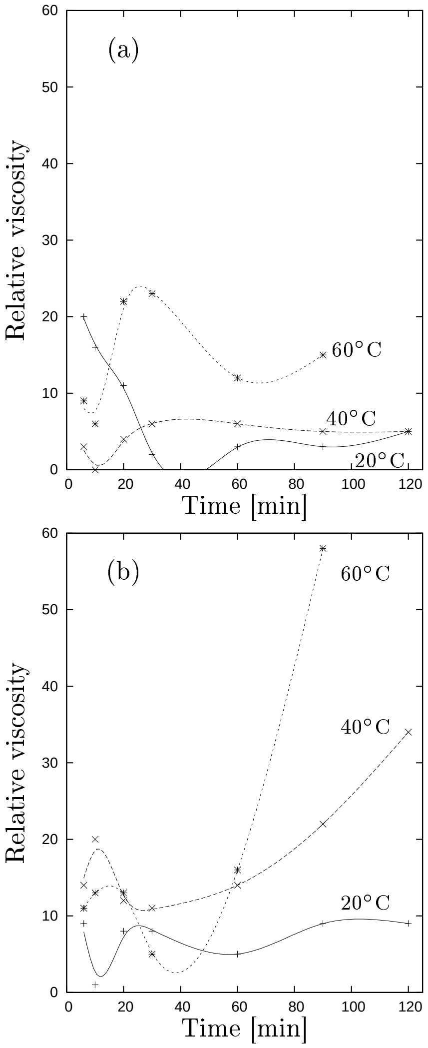

Figure 2: Viscosity of paste with the New Rheometer at three different temperatures, (a) Icelandic cement, w/c=0.8 and (b) Norwegian G-well cement, w/c=0.68

in the flow resistance curve (Fig. 1) than in the viscosity curve (Fig. 2) due to the higher scatter in the data in the latter. A higher data scattering in viscosity (corresponding to μ) than in the flow resistance (corresponding to τ_0) is often observed in cement based materials. This is due to the more sensitivity of H to small experimental error relative to the G value[5]. In this relation, the reader has to bear in mind that sometimes the flow resistance (Fig. 1) is relatively high while at the same time the viscosity value (Fig. 2) is low.

CONCLUSION

The workability loss is a strong function of time at elevated temperatures and may be represented as being $f(t,T)$. No fundamental difference between the workability loss of the Norwegian paste and the Icelandic paste was observed over the temperature range and time interval measured. The flow resistance of the Icelandic paste, however, increased seemingly faster than that of the Norwegian one as a function of time after one hour at an elevated temperature (40 and 60 °C) while the opposite was true for the viscosity. This may be explained, at least partially, by the different w/c ratio for the two pastes.

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