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Experimental study of salt content effect on class G cement properties with application to well integrity

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ABSTRACT

Cementing gas wells using salted cements is not a novel technique but the salt may affect cement properties in multiple ways by either accelerating or delaying the cement thickening time and also its mechanical properties. Well integrity during the life of the well remains the main function of the well cement. The continuous developments in petroleum engineering have led to well life extension beyond the conventional time, and thus cement properties are very important. As a result, the strength and composition, other mechanical properties of the cement are important to achieve a realistic design of a cement system. Today computer programs are used to predict cement behavior but the input data like compressive strength or Young's Modulus of the cement are very important in order to obtain the proper accuracy.

This paper shows the investigation of the effects of salt concentration on API class G cement. The analysis shows the variation of selected well cement properties like thickening time, compressive strength, the elastic or E-modulus and set cement permeability. For the first time, a reference work has been generated. The data produced by the experimental investigations aid in the optimization of cement design and are input data for numerical simulations of well cement performance. This research has proved once again that low NaCl salt concentration in low to moderate temperatures and pressures would have the highest accelerating effects on the hydration of Portland cement. Low concentrations of salt yield the greatest desired impacts on the speed of setting, development of strength, hydraulic integrity and rheology, but some adverse effects have been spotted when used in high concentration and at elevated temperatures (above class G cement threshold). In conjunction with the well integrity, the cement permeability at various salt concentrations (0–37% BWOW-By Weight of Water) has been also investigated and it could be observed that highly saline cement will generate additional permeability after setting which is not beneficial to well integrity.

1. Introduction

High amounts of salts have been used on purpose in well cementing since early 1950 to mitigate dissolution in massive salt environments (cementing practice in Golf of Mexico – GOM) that might otherwise jeopardize the cement sheath to formation bonding (Hunter and Tahmourpour, 2009). Moreover, salts are present in saline formation waters which are often used as cement mix water where fresh water is not available and are also present in seawater used as mix water in offshore cementing sites due to its ready availability. NaCl salt can impact the slurry behavior in multiple ways, according to some pioneers of salt cement research (Ludwig, 1951; Zhou et al., 1996; Erik and Nelson, 2006). As a versatile product, salt is applied to mitigate dissolution in massive salt zones and swelling of fresh water sensitive clays (Slage and Smith, 1963), as a cement freezing point depressant in permafrost zones or cold conditions (Rose et al., 1988) and above all as a hydration accelerator in the absence of $CaCl_2$. Compared to $CaCl_2$, other commonly used slats for well cements such as NaCl or KCl have shown less effectiveness of accelerating the process (Pang et al., 2015), however they may be used for other purposes as shown above. Moreover recent studies have shown that use of NCl for cements creates a less corrosive environment as the $CaCl_2$ (Pruckner and Gjørv, 2004). Believed to be capable of influencing

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cement behavior in multiple ways (Xi et al., 2010; Pang et al., 2015), and given the gaps in knowledge about the severity of the concentration dependent impacts, it is therefore critical to investigate the magnitude of the effects of NaCl concentration on the performance of cement. A well cemented casing serves as a mechanical barrier element of the well and properly designed cement is critical for the wellbore integrity (Slage and Smith, 1963; Shahvali et al., 2014). This paper is focused on experimental investigation of the effects of mix water salinity or NaCl salt concentration on some selected API class G cement properties. Class G cement is commonly used in Europe, and it is mixed with NaCl to account for salt-bearing reservoir fluids which are most common in some oil fields (i.e. Lower Saxony, Germany) (Lesti et al., 2013). Given the absence of an official industry consensus on salt slurry design (Erik and Nelson, 2006), these results will help fill gaps in knowledge about its reliability as a special additive used in solving some critical well cementing problems like those aforementioned. It would also aid in optimizing cement design and as a source of input data in performing numerical simulation of well cement. The tests carried out and the respective instruments used include slurry thickening time (atmospheric pressure consistometer), compressive strength (cement hydraulic press), Young's Modulus (laser Vibrometer) and permeability (permeameter). The procedure reference for most of the tests is the API spec.10A (2002).

2. Salt (NaCl) and Portland cement

In an optimal or appropriate amount, NaCl salts influence the slurry thickening/setting process, accelerate compressive strength, reduce slurry rheology, depress cement freezing point, mitigate swelling of fresh water sensitive shales (Slage and Smith, 1963), cause cement expansion, increase cement bond strength to salt formation (Erik and Nelson, 2006) and in high concentrations can downscale dissolution in massive salt environments and reduce Young's Modulus which can be beneficial for zonal isolation of underground Gas Storage (UGS) wells (Shahvali et al., 2014). Nevertheless, salt cement systems have also been known to have some limitations believed to be concentration dependent, e.g. their incompatibility with other additives and free water, and the mechanical and rheological behavior of the cement. It is therefore of the utmost importance to check the impacts of NaCl salinity on cement performance. Other salts are also used in cements, the most common one being $CaCl_2$ used mainly as accelerator (Herianto and Fathaddin, 2005; Pang et al., 2015).

The effectiveness or speed of Portland cement hydration dictates its mechanical and hydraulic performance: thickening time, compressive strength, E-modulus, rheology and permeability. In cold to freezing zones, accelerators are most often applied to hasten the hydration process thus reducing the Wait on Cement (WOC) time so as to be able to drill out soon and safely (Hunter and Tahmourpour, 2009). Besides $CaCl_2$, the common NaCl salt is one of the most often used and an ideal accelerator. Chemically, it can easily penetrate the C–S–H membrane, increase the permeability and the specific surface area of the C–S–H phase coating, change the C–S–H morphology to a more favorable structure (open and flocculated), increase the silicate anion polymerization and can also change the pore size distribution. Moreover, the speed of formation of fine crystalline Ettringite[1] is increased in the presence of chloride ions (Cl^-). Ettringite consumes the present gypsum ions by reducing them thereby accelerating the process of hydration. The cement hydration reaction is exothermic and the heat flow depends among others on the curing temperature. Heat of hydration in the range between 25 °C and 85 °C has been measured in moderate to high curing temperature conditions (Erik and Nelson, 2006). It has also been experimentally demonstrated that the heat of hydration increases with increasing curing temperatures and vice versa. It can be noted here that cement slurries treated with an optimal amount of NaCl accelerator and placed across formations with optimal temperature will have, among others, an increased setting speed and strength development. Nevertheless, the acceleration efficiency of NaCl in freezing conditions and the suitability of ordinary class G cement in such low to freezing conditions has not been investigated.

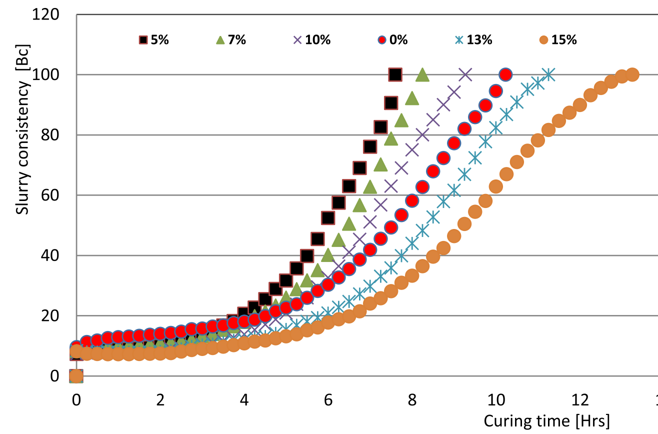

Fig. 1. Effects of NaCl concentrations on class G cement Thickening Time.

3. Effects of NaCl salt on API class G cement properties

Class G cement is very commonly used in Western Europe. Therefore, efforts have been focused on generating an accurate data package for this cement to be used as a reference. The class G Cement slurry composition had a water cement factor of 0.44 (44%) and no other additives except pure NaCl salts were added. The cement slurry was mixed according to API specifications. The density of the slurry used for experiments was 1.9–1.903 g/cm^3. Since no other additives were added and salt does not significantly affect the slurry density, the slurry obtained at 10% is similar with the API class G with 10% salt concentration as per Halliburton Red Book recipe.

3.1. Cement slurry thickening time

Cement slurry thickening time is also called the pumpability time and refers to the time duration over which the slurry remains sufficiently fluid and pumpable under specified curing temperature/pressure. The slurry thickness or consistency is measured in Bc units and a cement consistency of 70Bc to 100Bc is generally considered unpumpable. This test enables an estimation of the total time needed to safely mix and circulate the slurry into the well (annulus).

The prepared cement slurry (according to API 10B) is transferred from the blender into the slurry cup of the consistometer up to the reference mark, making sure the paddle is well positioned inside the cup. The cup is placed into the consistometer that has been preheated to the desired bath or test temperature (**28 °C/1atm**). Readings are taken at the start and every 15 min until a consistency of *100Bc*, i.e. end of Thickening Time (TT) test, is attained. The same is done to all the other slurry formulations correspondingly (8 different salt concentrations). The consistometer readings of all 8

[1] Ettringite: A hydrous calcium aluminum sulfate mineral with formula: $Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$.