Cement systems for oil and gas wells

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Primary cementing, the action of isolating the annulus between the casing of the well and the formation (the subterranean rock) is of primary importance in the construction of a well. It provides zonal isolation, i.e. it prevents the migration of fluids along the well, in effect re-isolating geological layers that have been connected during drilling.

Cementing follows directly the drilling phase. After a segment of a well is drilled, a large pipe is placed inside the hole and cement is circulated from surface, on the inside of the pipe, down the well, and back up through the annulus (the space between the newly drilled hole and the metallic pipe), Fig. 1.

At the beginning of the drilling process, the well is filled with mud, a complex mixture that is designed to match the naturally occurring formation pressure. More precisely, the hydrostatic pressure exerted by the column of mud should be more than the pore pressure (pressure exerted by fluids, such as hydrocarbons, in the pore space of rock), and less than the fracturing pressure (pressure at which the geologic formation will break down or "fracture."). Pressures of 70 MPa (≈700 atm) are not uncommon.

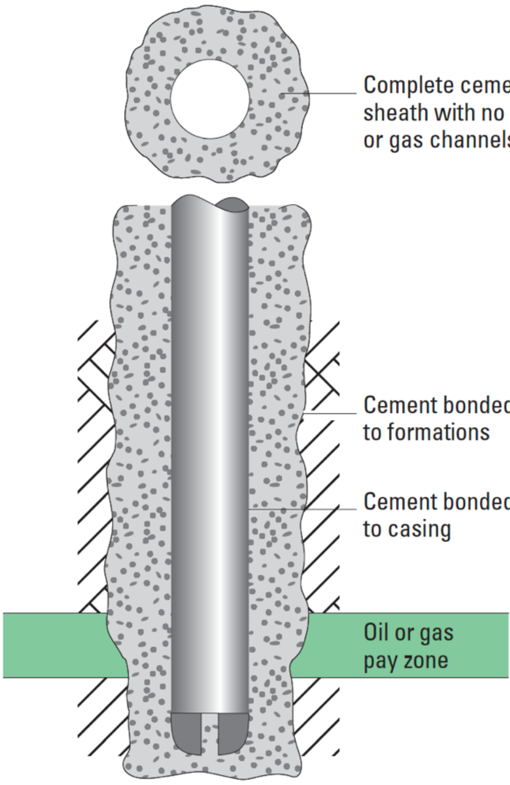

Fig.1 – Successful result of primary cementing operation- Cement completely fills the annulus, and is bonded to pipe and to formation From (Nelson & Guillot, 2006)

When pumped from surface, cement should displace the present mud, while also closely balancing its pressure between the pore pressure and the fracturing pressure. If the pressure exerted by the cement is too low, fluid present in the formation could leak to surface; If it is too high, it may break the formation. Slurry density therefore needs to be carefully adjusted. Slurry viscosity also plays a crucial role. If the it too low, cement may not properly displace the mud, creating leakage paths in the annulus. This could also happen if the pipe is not well centralized in the hole, creating smaller conduit where cement will not flow. If it is too high, cement slurry may fracture the formation, or the pressure applied at surface to circulate the cement slurry may reach the limit of the pump. During its travel, cement will experience varying temperature (surface to downhole temperature). This will influence its viscosity, gel time and setting time.

Finally, after it sets, the cement sheath should provide sufficient mechanical properties to sustain stresses in the well: casing expansion and contraction (pipe heats -expand- during production, cools down -contracts- when fluids are pumped from surface, and may contracts upon the release of hydrocarbon to surface, as the confining pressure of the rock will decrease), casing shear due to subsidence, etc.

Cement slurries recipes must take all the above factors into account. They may contain 10-20 additives: retarders (delay the setting time of a cement system), accelerators (reduce the setting time and increase the rate of compressive strength development), extenders (reduce slurry density), weighting agents (increase slurry density), dispersants (improve rheology by reducing the viscosity), fluid loss control agents (to avoid filtration if the cement slurry passes a permeable rock), lost-circulation control agents (minimize loss of cement slurry in a weak formation), etc. Other additives include rubber particles (flexible cement), nylon fibers (increase cement toughness), expanding agent (to counteract shrinkage). These additives may impact more than one property of the cement slurry, and may impact other additive's efficacy. Even more importantly, their effect may vary hugely depending on the cement type, including within a cement classification. Fig.2 illustrates this aspect.

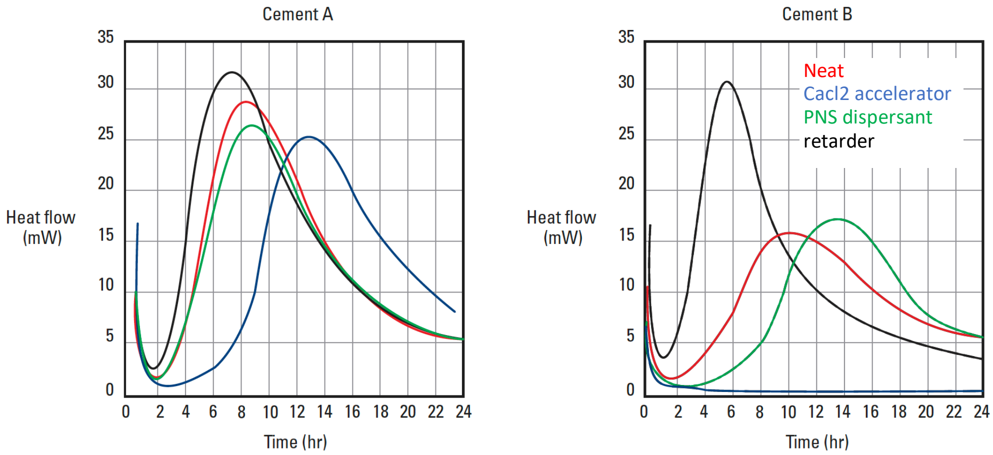

Fig. 2 – Calorimetry data for two different cements, with the same set of additives. From (Nelson & Guillot, 2006)

Other important parameters that influence additive performance include temperature (80-150 °C are typical temperatures), pressure, additive concentration, mixing energy, mixing order, and water-to-cement ratio.

Due to variability between wells, including neighboring wells, and variability in cement and additives, the recipes are customized to each well, each cement batch and checked for each additive batch. Cement labs are in charge of such design, and perform a set of slurry testing. Cement lab testing should be performed close to the well conditions (temperature and pressure). This significantly complicates testing setups and procedures. Typical tests include slurry density, setting time, fluid loss, compressive strength, sonic strength, free fluid, rheology, static gel strength, expansion and shrinkage, gas migration and permeability.

Finally, after cement has been placed and has set, its ability to properly isolation can be evaluated. Hydraulic tests can be performed: pressure in the well is increased or decreased, and one looks at pressure hold. Also, sensors can be run down the well to evaluate some properties of the cement annulus, using acoustic techniques.

Literature:

Well Cementing, 2nd Edition, Nelson & Guillot, 2006
Macondo, the gulf oil disaster, Chief Counsel's Report, 2011