Review of Well Cement Integrity Challenges and Monitoring Methods

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Abstract: In this study, well cement integrity challenges along with currently available methods for well integrity monitoring were reviewed. The challenges compromising well cement integrity begin from the time of mixing to placement and throughout the service life of the well. Research suggests that smart cement could possibly address these challenges due to it being a non-destructive, reliable and economic solution for continuous downhole long term monitoring of well cement operations.

1. Introduction:

Well integrity as defined by the Norwegian standard NOROSK D-010 (2013) is the "application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well." The integrity of cement sheath as a primary hydrocarbon fluids containment barrier is of growing interest in the oil and gas industry. The primary cement barrier is increasingly being challenged in reservoirs with hydraulic fracturing operations and with high-pressure and high-temperature (HPHT) conditions. Unanticipated gas leak and annulus pressure build up may have severe health, safety and environmental consequences. Hence, real-time monitoring of primary cement performances are active areas of research and study in the industry. This paper will include a review of the challenges in well cement integrity and current technologies used for monitoring well-cementing operations real-time from the time of placement and throughout the well service life. The limitations of these tools are also discussed including the fact that some of these methods are intrusive and may jeopardize the cement integrity without addressing the main issues such as tensile failure, locating the top of cement and wait on cement time. Most of these evaluation tools are usually run after the cement is placed whereas the most critical period is during cement placement at which most issues could be avoided if monitored accurately. Meanwhile, operators currently perform testing of cement formulations in the lab under simulated downhole conditions. However, these are idealized conditions and do not account for the complex conditions encountered downhole. Therefore, there is a need for a solution to bridge the gap between lab results and field operations and the only promising technology that may provide real-time monitoring solution for cement operations is smart cement. This cement exhibits sensing capabilities by means of measuring the change in electrical resistivity due to induced chemical, thermal and mechanical stresses known as chemo-thermo-piezoresistive effects. The novelty of the smart cement system is in its ability to continuously monitor the performance of well cement and visualize cement operational issues in real-time in order to provide immediate solutions preventing by that avoidable design and placement issues as well as future catastrophic issues leading to blowouts.

2. Objective:

The specific objectives of this study are the following:

a) Review available cement job evaluation technologies and highlight their limitations in cement failure and gas migration detection.
b) Describe Vipulanandan's smart cement and discuss its possible applications.
c) Compare different methods for cement integrity monitoring with smart cement.

3. Results and Discussion:

Table 1. Main Causes of Well Cement Integrity Failures

Well Cement Integrity Challenges	
Curing and Fluid Loss	• Under HPHT curing and fluid loss are hard to control. • Excessive fluid loss creates path for gas migration during placement and during wait-on-cement.
Contamination	• Mud contamination creates permeable cement (channeling).
Tensile Faluire	• Caused by temperature and pressure cycling. • Loading and unloading of fluids (Cyclic loading) during gas lift and production. • Most cements fail in tension (Dillenbeck 2005). • Rule-of-thumb tensile strength = 10% of UCS.
Debonding	• Due to lack of chemical bond between cement and casing as well as cement and formation (micro-annulus).
Shrinkage	• Autogeneous and chemical shrinkage (micro-annulus).
Chemcial Attack	• Acid stiumlation or production of fluids

The factors mentioned in **Table 1** all lead to potential gas migration either through the cement matrix, fracture in the cement or cement-casing/cement-formation micro-annulus. Most of the cement issues happen during placement and they become more complicated under HPHT conditions which could be prevented if the correct cement design was used coupled with a real-time monitoring tool to ensure optimum placement of cement behind the casing. These challenges could also happen after cement placement in the long term due to both mechnical failure and chemical attacks. **Table 2** below summarizes cement monitoring tools:

Table 2. Available Cement Integrity Monitoring Tools and Methods

Tools and Monitoring Methods	
Logging Tools (Cement Bond Log) CBL/VDL	• Logging tools are usually placed after the cement job • Can not detect foam and light weight cement • Acoustic signals attenuated in steel casing • Tool calibration and centeralization (eccentricity) essential for (major issue in HPHT horizontal wells) • Provides only qualitative description of hole condition • Errors due to interpretations and corrections required for BI

Logging While Drilling LWD	• Less downtime due to measuring while drilling • May facilate faster response to poor cementing due to measurement while cement is setting
Fiber Optic Sensors (Around casing)	• Localized readings (No bulk readings) • Hard to install and maintain during wells service life (2 or fibers) • Readings depend on installation mode and angle
Nano pipe treatment (Heathman et. al. 2017) Oceanit	• Nanotechonology pipe coating to improve acoustic cement evaluation.
Magnetic Cement System (Nair et. al. 2017) Univeristy of Texas	• Electromagnetic tool generating magnetic field capable of locating magnetic cement (Casing-cement bond detection).
Smart Piezoresistive Cement	• Real time monitoring of cement during placement and long term • No well intervetion needed and no expensive additives • Provides qunatitaive description of the hole (cement) condition • Proactive system

Table 3. Areas where zonal isolation is critical for operations

Zonal Isolation Challenges	
Plug and abandoment	• No effective monitoring system for abandoned well • Blowouts may happen even with strict regulations
Hydraulic Fracturing and Well Stimulation	• Cased hole stimulation damages cement (Mechanical and Chemical attack).
Enhanced Oil Recovery	• Carbonated waterflooding and injection of chemicals degrade the cement bechind casing
Extended Reach aand Offshore Wells	• Very expensive and high uncertainty of the cement job • Requires fast response to cement issues • Heavily regulated operations • Cementing problems maybe detrimintal to operations
Casing-Cement annulus (CCA)	• Due to lack of chemical bond between casing and cement • Attenuation of signals in casing

Lost Circulation	• Very costly to operators due to frequency of occurance • Identifying lost circulation zones is very challenging • Stopping lost ciruclation often result in wasted cement
Carbon Sequestration (storage)	• Long term and continuous exposure of CO_2 degrades the cement

Table 4. Functional Additives for Cement Integrity Monitoring

Cement Additives	
Smart Communicative Cement (Melo and Eid 2018) Ripsol	• Dispersed pressure and temperature sensing microchips. • Issues with dispersion and communaction between chips and modules on the casing.
Acoustically Responsive Cement (Pollock 2018) Oceanit	• Novel Composite cement modified with polymers to enhance acoustic signals for cement logging tools.

Table 5. Types of Models for the evaluation of well cement integrity during the life of the well

Cement Failure Models (Sanaude 2018)	
Analytical Model	Wilcox et al. 2016
Buoyancy driven mechanism	Frigaard and Crawshaw 1999
Finite Element mthod	Shahri et al. 2005
Probability model	Yuan et al. 2013
Thermo-poroelastic Analytical Model	Gholami et al. 2016

There is generally limited knowledge about the stresses downhole and the models mentioned in **Table 4** above should be simulated in a 3-D dynamic model (Sanuade 2018). Models generated for cement may use field specific data or laboratory generated test results which may not be applicable for all cement jobs. Hence a more practical real-time evaluation method would help understand and predict the cement job performance during placement and for the service life of the well.

4. Conclusion:

4. Smart cement is capable of detecting deformation in both tension and compression.
5. Smart cement could be used to detect early gel strength development which is very crucial for zonal isolation and protection from gas migration.
6. Compared to other monitoring methods, smart cement is currently the only promising technology

with the ability to monitor well cement operations both short term and long term in real time.

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