A Review of Real-Time Well Cement Downhole Monitoring Methods

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Abstract: This investigation serves to discuss well cement slurry placement and long term barrier downhole monitoring methods. It also lays down a review of the current monitoring methods available for operators as well as new and emerging technologies. The only technology that would provide operators with real-time continuous downhole data for cementing operations is the chemo-thermo-piezoresistive smart cement.

1. Introduction:

Long term well cement integrity and durability remain uncertain and far-fetched. Operators expect the cement barrier to support the casing, resist corrosion, withstand temperature cycling, and provide zonal isolation throughout the well's service life and after abandonment. Numerous cement designs and operational methods recommendations to prevent cement failure and annular flow were proposed in the literature. Yet, the ability to continuously monitor cement slurry performances downhole is an enduring technical and financial challenge that calls for real practical solutions. Even though new tools are emerging, none could measure hydraulic isolation and are predisposed to uncertainties and hereditary errors. The limitations of these technologies include, localized monitoring and intrusive techniques that may hinder the cement performance, fail to address the critical issues, and are merely surface indicators. Field evaluation tools are often run post cement placement forgoing by that cement placement issues, which plays a significant role in the sealing mechanism of the hardened cement. Meanwhile, testing of cement formulations in the lab to prevent gas invasion and produce durable cement involves using costly and advanced additives. These tests, however, are run under simulated downhole conditions, which may not accurately depict the complex environment downhole, signaling the need to bridge the gap between lab tests and field conditions. This study presents efforts to achieve this goal by reviewing the main challenges and highlighting the contributions in the literature and advancements in field-deployed technologies. Additionally, cement operational challenges from different parts of the world will be reviewed, along with an analysis of available field monitoring tools and a summary of their advantages and drawbacks. One thing remains certain, however, is that most wellbore integrity and zonal isolation issues and especially gas migration could be prevented if the cement operation were continuously monitored from the time of mixing and until the cement is placed in static condition downhole.

2. Objective:

The specific objectives of this study are the following:

a) Review available cement job evaluation technologies and highlight their limitations
b) Discuss gas migration pathways through well cement
c) Provide case studies and samples of cement field evaluations
d) Describe Vipulanandan's smart cement and its applications
e) Compare different methods for cement integrity monitoring with smart cement

3.1. Well Cement Integrity Challenges:

Table1 highlights recent major well blowout incidents due to loss of zonal isolation. One interesting finding was that none of these incidents had any sort of downhole monitoring method for both short term and long term. Also most cement downhole monitoring tools are not permanent may only measure the cement barrier after it hardends.

Table 1. List of Blowouts Caused by Uncontrolled Loss of Zonal Isolation

Date	*Location*	*Event*	*Remarks*
10/23/2015	Aliso Canyon, California, USA	Massive underground storage gas leak (blowout)	Carbon footprint larger than Deepwater horizon
8/17/2013	Bulla Deniz, Azerbaijan	Exploration well blowout catching fire	Overpressure zone while drilling a producing layer
7/23/2013	South Timbalier 220, Walter-Hercules, Houston, TX, USA	Loss of containment and control during side track (Leaked gas)	Unmanned platform
3/25/2012	Elgin Well G4, West Franklin Field, UK	Failure of primary barrier in a completed mature HPHT well (Loss of Containment)	Poor platform maintenance
4/20/2010	Deep Water Horizon, Houston, TX USA	• Cement barrier did not isolate hydrocarbons • Influx not detected until kick was in riser • Diversion to mud gas separator resulted in gas venting onto the rig	• Fire and gas system failure • BOP emergency mode seal failure • No cement bond log • Negative-pressure test accepted without well integrity establishment
8/21/2009	Montara Oil Spill Timor Sea, Australia	Oil and gas leak and subsequent slick	75 days gas leak
11/28/2004	Snorre A Well P-31A, Norway	Gas blowout occurred on seabed (gas on and under the facility during sidetrack)	Pulling out of hole gas kick
8/19/2004	Moss buff Cavern #1, Houston, TX, USA	Natural gas storage (major gas release and fire)	6 Bcf gas leak
Remarks	**Most incidents around Houston, TX, USA**	**Leaks could easily be controlled if detected**	**No available monitoring system**

3.2. Cement Evaluation Methods:

Since the introduction of the CBL tool in 1950, efforts into developing cement job assessment tools were targeted mainly towards post job analysis. The traditional cement evaluation tools used by operators in the oil and gas industry can be classified into two major classes: conventional sonic tools and modern ultrasonic tools (Gowida A. 2014). There are plenty of issues associated with conducting a logging job including costs, downtime, liability and the value of the data. Other issues include difficulty on interpreting signals in heavy and oil based muds, issues due casing eccentrecity and attenuation of signals in the casing. **Table 2** below provides a summary of currently used cement logging tools, new technologies along with their advantages and limitations.

Table 2. Available Cement Integrity Monitoring Tools and Methods

Logs		*Advantages*	*Limitations*
Acoustics	**Sonic (CBL/VDL)**	Predict cement bond and de-bonding	• Mud channels, vertical cracks, gas chimney, and radial variation in cement. • Eccentricity
	Ultrasonic pulse-echo (Imaging tool)	• Spatial resolution • Not affected by fluids • Provides cement map	• Sensitive to gas bubbles • Thick walled casing poor resolution • Mud channels and cracks in all directions
	flexural	• Detect light cement • Identifies cement to formation bond	• Casing thickness affects signals • Centralization
Temperature		• Top of cement (TOC) • DTS continuous and detects gas leak through multiple casing strings	• Ineffective in HPHT • Poor signal in long cement columns • Mud contamination affects results • Poor results for gas leak
Noise		• Combined with Temp log • DAS continuous and detects gas leak through multiple casing strings	• Hard to distinguish gas from liquid flows • Gas Leak poor resolution
Oxygen Activation		Detects channel flow velocity	• High activation energy requirement • Thermal convections affect the results • No field deployment yet
X-ray		Minimal HSE concerns (radioactive emissions can be turned off)	• Tool complexity • Generated heat management
Resistivity		• No HSE concerns • Material property	
Gamma-Gamma Density		• Compact tool design • Little heat management required	Disposal and handling of radioactive material
Pulsed Neutron		Works in highly deviated wellbores	• Fluids interfere with measurements • No field deployment
Remarks		• **Resistivity is a material property and distinguishes between different fluids, detect rates of flows, stresses, chemical and thermal changes** • **No HSE concerns for resistivity tools** • **Commercially available and low energy**	• **No commercially available permanent real-time and continuous downhole monitoring system** • **Qualitative not Quantitative Methods** • **Associated costs (downtime, logging tool cost and remedial cement jobs)**

3.3 Smart Cement

Most well integrity issues could be prevented if operational issues were appropriately monitored during placement. Unfortunately, up to this moment there is no method to monitor cement during all phases. Thus, cement systems equipped with built-in sensing capabilities that allow the visualization of cementing operations are of high demand as it is a time-sensitive operation. A self-sensing cement barrier that is sensitive to stresses, temperature cycling, and gas invasion forms a proactive system that replaces the reactionary measures and costly remedial cement jobs. Hence, providing operators with permanent downhole continuous monitoring capability to provide immediate solutions and prevent future operational issues. Such technology has been the holy-grail for operators, yet the detachment between research and operational needs remains a significant barrier. Vipulanandan developed smart cement by simply converting well cement designs into a logging tool that is sensitive to all changes from the time of placement and well after abandonment. Several sensing parameters were utilized to characterize cement behavior in the literature; however, some are material properties, whereas others are sample dependent. Resistivity, a second order tensor, was chosen as the monitoring parameter for smart cement as it is a sample independent material property. Resistivity is also sensitive to moisture content, chemical change, stresses and thermal cycling. Thus, smart cement provides a continuous real time quantitative method saving by that rig time while ensuring safety of operations.

4. Conclusion:

1. Logging tools provide qualitative indicators and generally may only be used after the cement sets.
2. Costs associated with downtime during logging tools deployment and remedial cementing could be avoided if a robust logging method was applied during placement.
3. 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.
4. Chemo-thermo-piezoresistive highly sensing smart cement is a permanent downhole monitoring system that provides real-time continuous quantitative data.

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