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Development of a structured workflow for enhanced well cement integrity: Lessons learned and the way ahead

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ABSTRACT

Despite the increased emphasis on enhancing short and long-term cement isolation, the oil and gas industry has not agreed upon a collective, scientifically supported blueprint to govern cement integrity standards. This is largely due to the fact that cement integrity and gas migration processes are influenced by an intricate assortment of transient elements, frequently occurring simultaneously. Ambiguity and insufficient information are an inherent component of drilling and production practices, but coordinated efforts and strategies can be instigated to minimize well integrity incidents.

To aid in the assessment and mitigation of cement failure probabilities, intricate risk analysis and assessment methodologies have been established in recent years. The original monitoring and evaluation framework developed in 2004 to assess long-term radioactive waste disposal has evolved into a multifaceted evaluation process to assess the safety and enduring integrity of carbon dioxide storage facilities. This methodology has changed little over the past decade, and has failed to incorporate transient events which typically occur during the lifespan of both producing and abandoned oil and gas wells.

With this in mind, a unique and systematic procedure is required to assess the array of dynamic factors which have proven to adversely affect the cement integrity of oil and gas wells. A data matrix consisting of a combination of cement, lithological, thermal, and hydraulic information must be employed to extensively evaluate cement integrity (Lavrov et al., 2014). From this input, a consequence analysis will be provided to assess the risks involved from disorganized and faulty cementing practices and techniques. This paper proposes an extensive literature review of currently published attempts to evaluate cementing integrity, and the necessity of a more expansive construct to evaluate long-term primary and secondary cementing environments.

1. Introduction

The cementing process is conceivably the most important operation performed during the drilling and production cycles of an oilwell (Teodoriu et al., 2015). In recent years, well integrity issues involving gas migration have gained notoriety due to criticism from social media, sensationalized reports and documentaries, and fervent environmental groups (Darrah et al., 2013, 2014). Numerous studies and experiments have been conducted in an effort towards enhancing cementing strategies and procedures to mitigate well integrity issues, but gas migration issues continue to plague the industry (Kutchko et al., 2012; Nikolaus et al., 2009).

It has been proposed by Dusterhoft et al. (2002) that approximately 15% of all primary cementing jobs in the United States fail at some point during their lifespan. Gas and/or fluid migration were the principal cause of at least one-third of these cement failures (Dusterhoft et al., 2002). Historically, oil and gas cement schemes were designed to provide a durable barrier for 40–50 years, but failure risks after this time period were never given proper consideration (Fig. 1).

Optimum cementing design, procedures, and testing create the essential hydraulic obstacles to avert both gas and fluid migration, and are the most effective means of mitigating environmental pollution (Kutchko et al., 2012; Nickolaus et al. 2009). The oil and gas industry has a substantial need to define the physical and chemical constraints required for a cement system to be considered “gas tight”. Additional research is required to outline the defining characteristics and driving forces behind gas migration in primary

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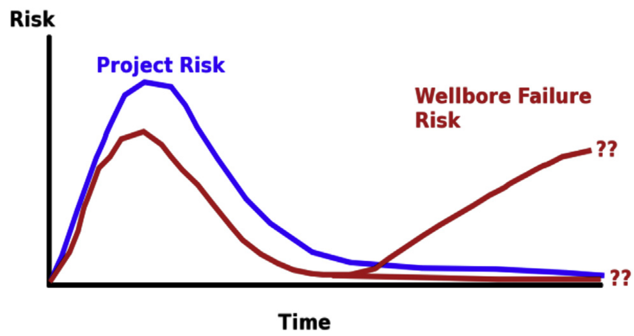

Fig. 1. Projected vs wellbore failure risk (Carey, 2010).

and remedial cementing applications, and understanding the capabilities of current cementing technologies to inhibit gas migration (Hunt, 1979; Watson, 2004, Watson and Bachu, 2007). There are currently no defined laboratory experiments or cementing standards available that provide even a generalized prediction of gas migration (Nelson and Guillot, 2006).

Over the last decade, numerous studies have been conducted to assess the risks and possible causes of gas migration in CO2 storage wells (Zhou and Wojtanowicz, 2000; Wildenborg et al., 2005; Bachu and Watson, 2006; Le Guen et al., 2008; Reinicke and Fichter, 2010). These studies, however, focused exclusively on the inherent issues involved in the geological storage of carbon dioxide, specifically the detrimental effects of CO2 saturated brine on cement degradation. Oil and gas well integrity has received far less attention, despite the vast assortment of advanced cement evaluation and monitoring tools currently available.

In order to assuage public concern, and provide the petroleum industry with a practical assessment for successful cementing operations, an integrated process utilizing a combination of industry accepted methodologies is required (Detlefs, and Chastain, 2012; Bai et al., 2015). The modified workflow (Fig. 2) incorporates three interconnected, yet transient components: Features, Events, and Processes (FEPs), analytical and mechanical modeling (Finite Element Modeling), and a risk/consequence analysis. The results obtained from these evaluations would then provide a thorough well integrity synopsis, which could be incorporated into an accessible, online database readily available to the public.

The first step involves analyzing all features, events, and processes that might potentially alter the long or short-term well integrity environment. After carefully collecting and selecting relevant data, Finite Element Method (FEM) software will be utilized to systematically analyze the cement's performance under loading conditions typically observed throughout the expected life of the well. Experimental data on fatigue and long term behavior is used to validate and extend the FEM results. Lastly, a consequence analysis will be generated based on the unique parameters and transient well and cement variables. A decision making schematic will then be populated, outlining the relevant short and long-term risks associated with the given wellbore scenario.

1.1. Primary and secondary cementing overview

The foremost goal of any oil and gas cementing application has always centered on providing both short and long-term well integrity. NORSOK defines well integrity as the “Application of technical, operational, and organizational solutions to reduce risk of uncontrolled release of formation fluids and well fluids throughout the life cycle of a well” (NORSOK D-10, 2013). Within the construct of cementing processes, attaining well integrity involves the successful application of complex principles in both primary and secondary cementing applications.

Primarily composed of methane (Hunt, 1979), shale gas migration has been an industry wide problem for decades. Gas migration, also commonly referred to as casing vent flows or sustained casing pressure (SCP), requires two cooperative factors: a conduit or channel permitting gas to flow, and a formation fluid (gas or liquid hydrocarbon) in the pore space driven through a pressure differential (Watson, 2004; Prohaska et al., 1993). The latter condition is an intrinsic state of downhole fluids; our objective, then, is to optimize cement design and practices to successfully prevent this permeable channel.

Primary cementing is an essential part of drilling and completion operations, and involves inserting a cement sheath around a

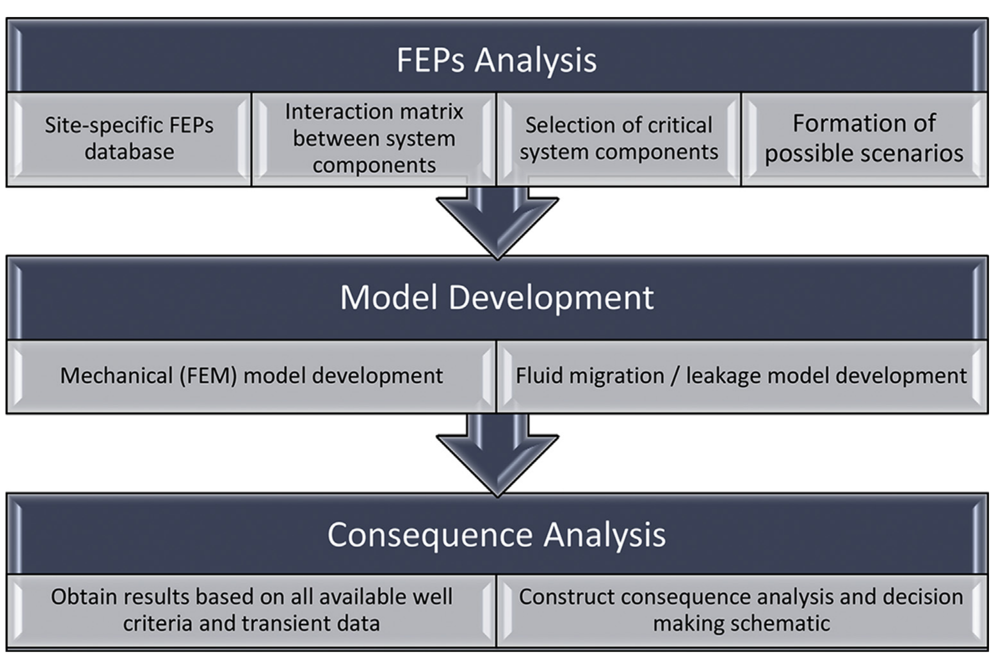

Fig. 2. Well integrity evaluation flowchart.