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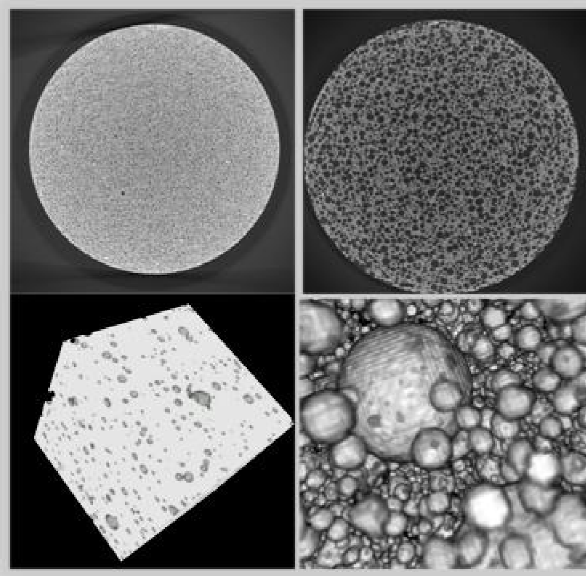

An Assessment of Research Needs Related to Improving Primary Cement Isolation of Formations in Deep Offshore Wells

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Cover Illustration: CT scanner images of various foamed cement prepared and taken by NETL researchers.

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An Assessment of Research Needs Related to Improving Primary Cement Isolation of Formations in Deep Offshore Wells

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Acronyms and Abbreviations

Term	Description
API	American Petroleum Institute
DEA	Drilling Engineering Association
DOE	Department of Energy
ECD	Equivalent circulating density
GOM	Gulf of Mexico
IADC	International Association of Drilling Contractors
NETL	National Energy Technology Laboratory
ORD	Office of Research and Development
R&D	Research and development
RUA	Regional University Alliance
SPE	Society of Petroleum Engineers
TIG	Technical Interest Group

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1. EXECUTIVE SUMMARY

This report summarizes the findings of a six month National Energy Technology Laboratory (NETL)-led review of the current state of knowledge regarding research needs and potential knowledge gaps as they relate to current-day cementing practices and conditions of offshore wells. This review incorporated information from scientific and technical literature, feedback from various industry professional organizations, input directly from industry experts associated with the cementing of offshore wells, as well as results from a two-day workshop. Research needs were evaluated in terms of the development of improved tests needed for operators and regulators, filling key data gaps needed in assessing risks or potential failures, and key elements in quality control that could negatively impact performance.

Wells in the Gulf of Mexico (GOM) are being drilled in increasingly extreme environments, in water depths exceeding 9,000 ft and subsurface targets in excess of 20,000 ft below seafloor. As a result, cement barriers in offshore wells are subject to a variety of temperature, pressure, and in situ fluid and formation conditions. The findings in this report represent important knowledge gaps that require research and development (R&D) to improve safety and reduce risks associated with offshore cementing jobs. A number of findings suggest there are knowledge gaps in assessing the quality and reliability of the cement before it is placed in the well. Several findings suggest there may be a disconnect between the way cement is tested in the lab and the conditions it is subjected to in the wellbore and that industry currently lacks reliable means to monitor the cement once placed in the well.

2. INTRODUCTION

The National Energy Technology Laboratory's (NETL) Office of Research and Development and its Regional University Alliance (NETL-RUA) conduct research related to deep offshore hydrocarbon development under the Complementary Program of Title IX, Subtitle J, Section 999A(d) of the Energy Policy Act of 2005 (EPAct 2005). The focus of the Section 999 program began to shift in 2010 after the April 2010 Macondo Prospect oil well blowout and resulting spill in the Gulf of Mexico (GOM). Interest grew at the U.S. Department of Energy (DOE) in focusing on the technical basis for assessing and mitigating risks associated with safety and environmental aspects of deepwater oil exploration and production. The overall objective of this body of work is to advance scientific understanding and build the assessment tools necessary to develop the confidence that key domestic oil and gas resources can be produced safely and in an environmentally sustainable way (DOE NETL, 2012a, 2012b).

Since 2011, the Complementary Program's research portfolio has included research related to improved understanding of the integrity and longevity of offshore borehole cements. In the United States, the majority of offshore hydrocarbon production comes from the GOM where cementing practices vary across the shallow shelf to deepwater (up to 10,000 ft water depth) basin both with regards to the type of cement emplaced as well as the methods and practices used. In 2007, Izon et al. reported that cementing problems were the top factor contributing to blowouts in the GOM from 1992 to 2006 (see Figure 1). As the breadth and scope of cementing practices continues to evolve, particularly as drilling continues to pursue deeper targets, both water depth and subsurface, the initial and long-term integrity of cement barriers and the protocols for emplacing them are key to safe and productive operations.

Since the Izon et al. study in 2007, drilling operations in the GOM have targeted increasingly extreme environments, in water depths exceeding 9,000 ft and subsurface targets in excess of 20,000 ft below seafloor. As a result, cement barriers in offshore wells are subject to a variety of temperature, pressure, and in situ fluid and formation conditions; in addition, the formulation of cements utilized in the GOM varies. In this report, we identify key research needs and potential knowledge gaps as they relate to current-day cementing practices and conditions of offshore wells. The stability of wellbore materials is of extreme importance to the safe construction of ultra-deepwater wells for deep oil and gas production. This report identifies key research needs related to enhancing the success of cementing practices commonly utilized in ultra-deepwater well completion systems. The information developed for this report was drawn from a literature search, feedback from various industry professional organizations, and input directly from industry experts associated with the cementing of offshore wells.

This report details five key research findings based on a six month NETL-led review with respect to operational issues in cementing offshore wells. These findings represent significant knowledge gaps that require research and development (R&D) in order to provide sound science for both industry and regulators to improve safety and reduce near and long-term risks associated with offshore cementing jobs. These findings suggest there are knowledge gaps in assessing the quality and reliability of the cement before it is placed in the well and reliable monitoring post-placement. Several findings suggest there may be a disconnect between the way cement is tested in the lab and the conditions it is subjected to in the field (offshore wellbore conditions) and that industry currently lacks reliable means to monitor the cement once placed in the well.

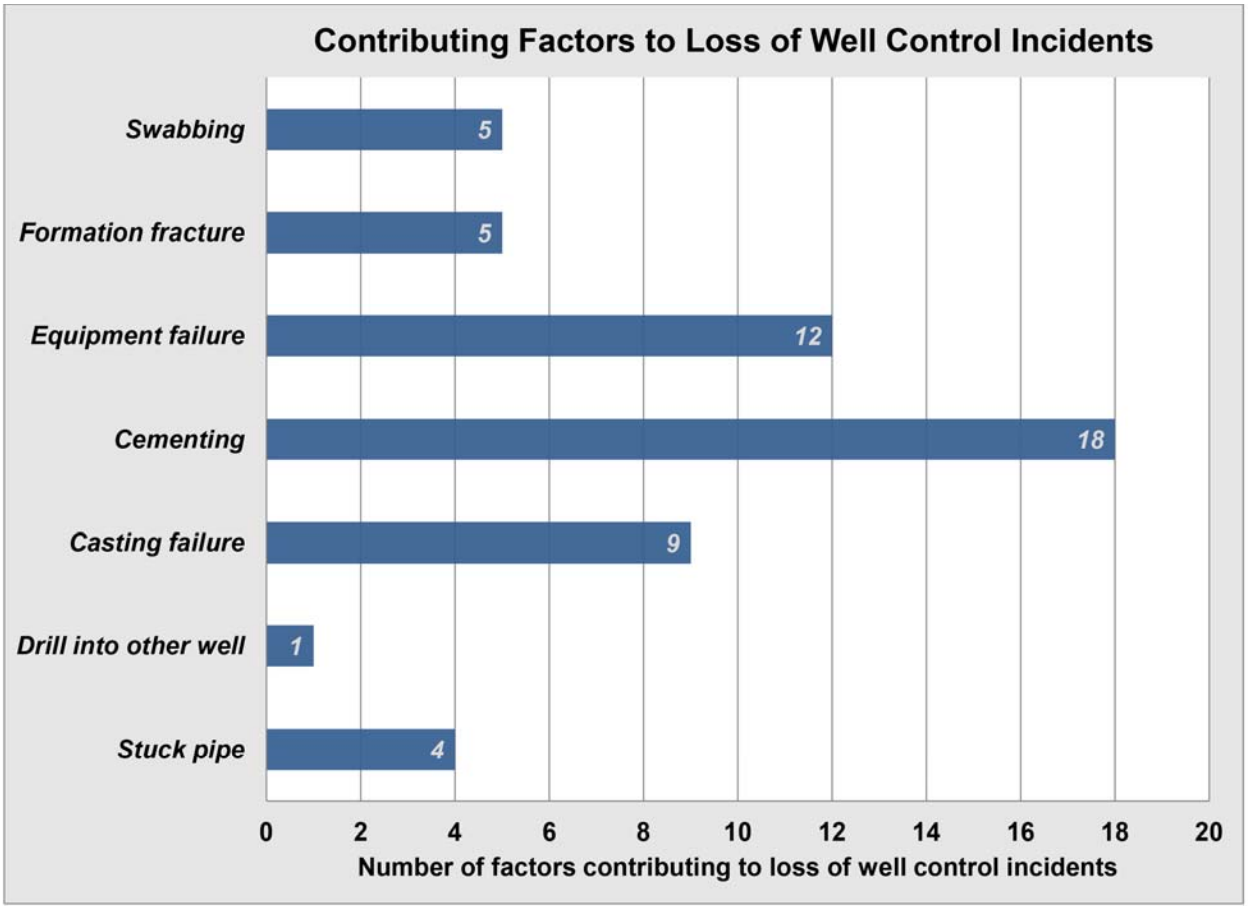

Figure 1: Data from offshore operations in the Gulf of Mexico spanning 1992 to 2006 clearly demonstrates the significant role cement barriers play in ensuring safe and productive operations during the drilling and completion phase of a well (Izon et al., 2007).

3. LITERATURE AND INDUSTRY EXPERT REVIEW

The purpose of this report is to summarize the findings of a six month NETL-led review of the current state of knowledge relating to offshore cementing practices, in particular in deep offshore environments. The effort integrated existing information from publically available scientific and technical literature, with comments provided by industry experts, and results from a two-day workshop. Research needs related to potential knowledge or technology gaps in current offshore cementing practices were evaluated in terms of the development of improved tests needed for operators and regulators, filling key data gaps needed in assessing risks or potential failures, and key elements in quality control that could negatively impact performance. The solutions to problems in obtaining good primary cement jobs (i.e., that effectively isolate formations behind pipe from one another and the annular space above the cement top in a way that meets the objectives of the well) can be generally categorized under one of the following:

- Improvements to the Process – Finding more effective ways to consistently do what is needed operationally to get a good cement job. This may include better standards or new procedures and protocols, as well as new technologies.
- Overcoming Data Quality Limitations – Finding more effective ways to obtain more accurate or more representative data needed to design, implement, and evaluate a cement job.
- Improving Predictive Tools – Developing better models (simulators) for understanding the physics of cementing and for predicting the impact of different designs and operational methods.
- Developing Additional Basic Data – Acquiring additional fundamental data from laboratory or field testing that can be useful in supporting all of the above.

The companies involved in offshore exploration and development and the major service companies that support them are aware of the challenges of obtaining good cement jobs and continue to focus a great deal of effort on finding ways to improve performance in this area.

The following report is based on a combination of information compiled from existing scientific literature and technical conversations with various industry experts on the topic of offshore borehole cementing. An industry expert was defined as someone with strategic knowledge, insight, and significant experience in drilling and cementing. The industry experts spoke on the condition that they remain anonymous. Industry experts from a variety of major oil and gas and service companies were consulted by NETL personnel with experience in drilling and cementing. NETL personnel contacted members of the American Petroleum Institute (API), International Association of Drilling Contractors (IADC), Drilling Engineering Association (DEA), and the American Association of Drilling Engineers. Industry experts were asked to detail their concerns about the current state of cementing technology and areas in which further research and development is needed. The comments below represent their collective concerns as synthesized by NETL-ORD borehole cementing researchers who evaluated the collective body of input for accuracy, consistency, and broader implications in relation to the goals of this report.

In addition, NETL researchers conducted a two-day, in house planning workshop with a drilling and cementing industry expert, Glen Benge. Benge has 34 years of experience associated with all aspects of drilling and cementing and has authored numerous papers on all aspects of cementing design and application. The workshop covered drilling and cementing operations, as well as operational issues during and immediately after drilling. The workshop focused on cement stability issues, cement evaluation techniques, the importance of zonal isolation, and specialty cements commonly used in wells drilled through the flow zones prevalent in the Gulf of Mexico. During the second day, NETL researchers discussed analytical and experimental plans for research related to the evaluation of deepwater cementing practices in order to reduce risks and potential environmental impacts related to cementing failures in these systems.

A number of topics clearly stood out with relation to cement design, placement, and long-term integrity. The stability of wellbore materials is of extreme importance to the safe construction of wells for deep oil and gas production. In particular, it is crucial that the primary cement job is sufficient to maintain structural integrity and complete zonal isolation of the wellbore. The objective of this assessment is to understand the current state of knowledge on the long-term performance of these materials for the deepwater environment. Throughout the discussions and literature search, five primary issues surfaced. Listed in order of priority they are: 1) failure to monitor cement placement and integrity in the long term, 2) better understanding of cement stability under field conditions, 3) cement quality control, 4) the design of cements for frequent stress loading and unloading events post placement, and 5) the lack of industry standard calculations to determine cement characteristics and properties.

3.1 FAILURE TO MONITOR CEMENT PLACEMENT AND CEMENT INTEGRITY IN THE LONG TERM

Individual expert responses, and certain examples in the literature, noted that the mechanisms of cement failure are not well constrained. A part of this is related to inadequacies in monitoring cement placement (i.e., is the cement where it should be?) and its long term integrity (Ravi and Bosma, 2002). All of the experts noted that there is little understanding of how effectively cement sets across zones and, more importantly, the duration and efficacy of its integrity over time. All agreed that long-term monitoring of zonal isolation performance is a paramount need within the industry to better understand the performance of cement over time; however, current tools and techniques are inadequate either due to cost or lack of appropriate options. Specifically noted was the need for better technology to demonstrate and monitor isolation over the life of the borehole.

Findings: Research needs include the development of a tracer that could be pumped with the cement and measured after it had set, tools to efficiently and accurately survey cement bond logging, and in situ sensors to evaluate integrity.

3.2 BETTER UNDERSTANDING OF CEMENT STABILITY UNDER FIELD CONDITIONS

The lack of understanding of cement stability under field conditions can lead to uncertainties in risk assessment. The issue of cement stability under field conditions is a concern both *during* *placement* and *post placement*. Cement stability during placement concerns include fluid loss control, contamination (fluid/fluid displacement and the effect of drilling fluid), and dynamic settling. The dynamic stability of cement fluids (what happens when the fluid is moving) is not well understood. For example, it is uncertain if there is separation of light and heavy particles during cement pumping. Post placement concerns include cement expansion and/or shrinkage, development of free water, temperature and pressure stability (permeability changes and strength retrogression), hydration, gas and fluid migration, fluid loss, and cement/formation interaction (de Rozieres and Ferriere, 1991; Tellisi et al., 2005; Reddy et al., 2007; Ravi and Bosma, 2002; Creel et al., 2006). Experts specifically mentioned that industry lacks an understanding of the effects of shrinkage and expansion, an understanding of foamed cement stability, and requirements for gas migration prevention in the wellbore environment.

Changes in the physical volume of the set cement (expansion or shrinkage) can affect the long-term seal of the wellbore annulus (Goboncan and Dillenbeck, 2003). Cement shrinkage leads to debonding between the cement/casing or cement/formation interface leading to the formation of microannuli. It can also cause tensile cracks to form which effectively lower cement permeability. These can both provide a route for gas and/or fluids to flow (Reddy et al., 2007; Bonett and Pafitis, 1996). Understanding shrinkage and expansion and how they affect long-term wellbore integrity and zonal isolation is considered an important operational issue.

Foamed cement systems are of interest post Macondo. Foamed cement is used globally in deepwater (Benge and Poole, 2005). It is the system of choice for high stress environments and shallow flow conditions such as those prevalent in the GOM (Benge and Poole, 2005; Leuranguer et al., 2006; Martins and Campos, 1994; Judge and Benge, 1998; Moore et al., 2000; Degni et al., 2001). Other contributing factors include the ultra low seabed temperature encountered in deepwater wells, extreme pressure cycles, and low fracture gradients (Taiwo and Ogbonna, 2011; Benge and Poole, 2005; Rae and DiLullo, 2004; Griffith et al., 2004; Kopp et al., 2000). However, there is a significant lack of understanding of the stability of foamed cement under wellbore conditions (Ravi and Bosma, 2002; Mueller et al., 2004; Griffith et al., 2004; Heinhold et al., 2002; Boukhelifa et al., 2005; de Rozieres and Ferriere, 1991; Garcia et al., 1993; Thayer et al., 1993). Currently the testing of foamed cement is done under atmospheric conditions. However, designing foamed cement systems requires a good understanding of the influence of parameters such as temperature and pressures. There is only one laboratory study published that examines foamed cement under pressure conditions (de Rozieres and Ferriere, 1991). Unstable foamed cements can result in the loss of zonal isolation and wellbore failure. As such, API is currently revising their Recommended Practice on testing of foamed cement systems.

Industry has a significant need to define the parameters required for a cement system to be considered gas tight. This is especially critical when drilling and cementing in environments with shallow stray gas and/or fluids. The research needs include defining the properties of gas-migration in cements and understanding the ability of currently used cements to prevent gas migration. Laboratory experiments that provide generalized and quantitative prediction of gas migration are not currently available (Nelson, 2006). One industry expert stated that new regulations call for the adoption of “gas tight” or “gas migration prevention” slurries for use in upper casing strings. This means a cement system is needed that has low fluid loss and no free water. While tests, including static gel strength development and gas migration, are available they are not considered standard because they are not consistent throughout the industry. Research into gas migration prevention slurries would involve an evaluation of systems that, while they may have no free water and low fluid loss, may have longer transition times (time between the fluid and set state of the cement) that would in fact be detrimental to gas migration prevention. Currently there are systems designed that rely on thixotropic behavior to control the gas migration. Thixotropic behavior is a property by which certain gels become fluid when disturbed (i.e. shaken).

Findings: Further research, under field conditions, of cement setting and stability parameters would help identify key elements for cement design, which would be utilized by API to develop new standards or update existing best practices to ensure safe wellbore operation (Goboncan and Dillenbeck, 2003). This includes research on the stability of foamed cement systems as they are placed in the well and post-placement. The increased use of foamed cement in high-stress environments makes understanding their stability vital. Foamed cements are currently tested in the laboratory at atmospheric conditions making correlations to the wellbore environment uncertain. Research is needed to look at thixotropic systems and their role in the process. This is not a subject that has a lot of work behind it and thus could benefit from additional research.

3.3 CEMENT QUALITY CONTROL

Industry experts and literature research indicate that there is often a disconnect between cement as tested in the laboratory and as mixed and pumped in the field (Creel et al., 2006; Thayer et al., 1993). Contributing to this disconnect is the condition of bulk cement after mixing, shipment and transfer and, particularly, an inability to recreate job site conditions (hole conditions, pumping parameters, pressures and temperatures) in the laboratory. As a result, the job as modeled in the laboratory is often not the job pumped. For example, little is understood regarding the effects of settling during transportation, the influence of particle shear as the cement is blown and pumped, the different behavior of laboratory and field mixers, and a number of other factors. Also, while it is possible to measure free water in the lab, industry lacks a suitable technique for scaling the measurement up to actual jobs. One expert noted that the cement pumped on the job is almost never a replica of that tested in the lab and that conditions as the cement is pumped are not fully understood. Cement tested in the lab may appear to be sufficient for the job; however, the cement actually pumped may not be adequate to do the job.

Findings: Research focused on quantifying the potential impact of poor quality control, or on developing improved “best practices” for insuring that cement pumped is the same as cement tested, should be a high priority. Since the April 10, 2010 Deepwater Horizon drilling rig explosion, there is increased need to thoroughly test each cement design, meaning that new laboratory procedures and testing equipment are needed to keep up with demand for cement testing. The frequency of lab testing has increased dramatically and there is a need to design ways to improve, simplify, and possibly automate testing technology.

3.4 DESIGN OF CEMENTS FOR FREQUENT STRESS LOADING AND UNLOADING EVENTS POST PLACEMENT

Changes (cycles) in pressure and/or temperature in the wellbore can cause mechanical failure, the development of microannuli (potential flowpaths), or loss of zonal isolation. Cements must be able to withstand multiple stress cycles and maintain integrity (Boukhelifa et al., 2005; Heinold et al., 2002; Griffith et al., 2004; Mueller et al., 2004; James and Boukhelifa, 2008). Under scenarios of anticipated repeat stress cycles, more flexible cement such as foamed cement systems is desired to prevent early failure (Griffith et al., 2004). Research and development of alternative cements/well isolation technologies should be considered for application in high risk, high stress cycle applications.

A significant area of this research lies in ultradeep offshore wells. Ultradeep offshore wells are large heat exchangers. There are temperature uncertainties as cement goes to the bottom of a well and comes back up the annulus and cools. In deep and ultradeep water work, there is a lack of understanding of the temperature recovery of the well. Accurate temperature determination is essential to cement slurry design. There must be a better understanding of thermal cycling effects of cement during placement and upon setting in ultradeep and deep offshore wells. Wellbore thermal modeling will become more important as deeper wells are drilled.

Findings: Research is needed to focus on the thermal and pressure stress cycles in ultradeep offshore wells. Wellbore thermal modeling is needed to understand temperature uncertainties.

3.5 LACK OF INDUSTRY STANDARD CALCULATIONS TO DETERMINE CEMENT CHARACTERISTICS AND PROPERTIES

A number of comments, both in the interviews and in the literature review illustrate that while tests may be available, many are not considered standard tests because they are not consistent throughout the industry. This includes static gel strength and gas migration tests—important parameters needed to determine the appropriate cement system used in the well environment. In addition, the industry lacks a standard stress calculation for set cement. While models calculate induced stress values in compression and tensile components, much of the higher temperature tests of the mechanical properties of cement only include cement flexural strength tests (Heinold and Dillenbeck, 2002).

Findings: Research to develop a set of “industry standard” tests of cement properties is a significant focus of investigation by oil-field service companies for the writing and updating of API standards and recommended practices.

4. CEMENT FAILURE ISSUES

The discussion below focuses on parameters for cement design and placement and cement failure mechanisms. In general, cement is subject to failure in three modes: at the cement-casing interface, at the cement-wellbore interface, and within the cement body. Cement failure can also be categorized into three time frames: immediate (during placement), short-term (post placement), and long-term (after the cement hydrates). A number of factors can contribute to, or cause, failure in any of these modes. Issues were identified through a review of the literature and by various respondents in Society of Petroleum Engineers (SPE) Drilling and Completions Technical Interest Group (TIG) discussions (Heathman, 2008) to avoid cement failure, with comments taken from additional sources.

Cement Slurry Design and Mixing

Cement failure can occur if slurry design considerations are not met. Designs for an expedient cement job and cement integrity are often not compatible, or the optimal use of cement and additive chemistry is not achieved. Bulk blending needs to be rigorously controlled and monitored. Wear in grinding equipment may result in cement particle sizes not in accord with bulk cement requirements. Cement may settle during bulk transport, effectively changing its characteristics by altering particle distribution in the bulk cement. When mixing and pumping any cement slurry, especially foamed cement slurry, it is imperative to ensure that the slurry is mixed and pumped consistently at the designed density. This requires full time monitoring and control of mixing volumes, and additive injection and nitrogen injection volumes and rates. The ability to change injection volumes must be clearly understood. This process is generally automated. Other cement design parameters of importance to proper cement stability are the type of cement, quality of the mix water (chemical composition, pH, TDS), additives, density, viscosity/rheology equivalent circulating density (ECD), and thickening time (Heinhold et al., 2002; Martins and Campos, 1994).

Cement Setting Behavior

Cement setting behavior should be described by its compressive strength and elastic properties. Other important parameters are the contracting and thermal behavior of the cement. Very few data have been published on these topics in literature. In order to avoid the creation of micro-annuli it is important to understand the initial state of stress in cement sheaths, the contracting behavior of cement systems, and the poro-mechanical behavior of cement systems. Test protocols are needed to measure all the parameters used in models, including Poisson’s ratio and coefficients of thermal expansion (Bois et al., 2011; Reddy et al., 2007). Failure to achieve appropriate compressive, tensile and elastic strength, in addition to appropriate porosity, will result in cement failure. Failure in these areas can result from poor job design, pumping regimes, or through interaction with cement and various chemical reactions within the cement constituents and between the cement and the formation (Bois et al., 2011).

While it is possible to measure free water in the laboratory, industry lacks suitable techniques for scaling the measurement up to the actual job. Free water can lead to settling of solid particulate which in turn will lead to the formation of areas in the cement sheath with higher relative percentages of cement and of areas with higher water concentrations. In areas with higher water concentrations, the cement permeability goes up and the strength is reduced.

For light-weight cements in deepwater applications, short liquid/solid transition time, low set permeability and good ductility are more important than strength, per se, for long-term integrity of the well. As mentioned earlier, there is a significant need for increased wellbore thermal modeling. Currently, there is a very poor understanding of the thermal recovery of the well from circulating to static temperature. Other considerations include expansion/shrinkage, hydration/free water, setting time, as well as compressive strength and elastic properties (Young's Modulus and Poisson's ratio) (Reddy et al., 2007; Ravi and Bosma, 2002; Tellis et al., 2005; de Rozieres and Ferriere, 1991; Mueller et al., 2004; James and Boukhelifa, 2008).

Downhole Conditions

Hole quality can vary considerably. Factors that may affect cement integrity include wash outs, reactive zones, fluid/fluid displacement, and a poorly conditioned hole. Wash outs that increase annular volume may put placement of cement across zones of interest in jeopardy. Reactive zones, such as shale, may swell or otherwise interact with cement to weaken the cement/formation bond. Residual mud in the hole (fluid/fluid displacement) may adversely impact cement integrity due to chemical interactions. Oil residue from oil-based mud, for example, can act as a defoaming agent in the presence of foamed slurries. A poorly conditioned hole containing cuttings and/or sloughed formation materials can prevent cement from bonding with certain formations and/or contaminate cements.

Mud filter cake quality is a significant concern. During the drilling process drilling mud used to lubricate and circulate cuttings, fluids and gases out of the borehole can accumulate as a rind on the borehole (full definition of filter cake at http://www.glossary.oilfield.slb.com/Display.cfm?Term=filter%20cake). Depending on the permeability of the formation itself, drilling mud and fluids may also invade or filter into the formation as well as accumulate on the borehole/formation interface. Ideally, according to the SPE Drilling and Completions TIG discussions, mud filter cake should be thin and impermeable. Unsuitable mud filter cake (thick or permeable) can weaken or prevent cement bonding to the wellbore.

Formation type needs to be considered when choosing drilling and cementing fluids as they may affect formation integrity (Ladva et al., 2005; Heathman, 2008). For example, drilling through water-soluable formations is a concern due to their high solubility which may lead to well washouts (Heathman, 2008). With regard to cementing in shales, the bond between swelling shale and cement can be weak. The position of the fracture plane alternates between the shale and the cement, depending on the drilling-fluid pretreatment that the shale received (Bois et al., 2011; Ladva et al., 2005). Chemical alteration of bentonite filter cake and the setting cement can affect the interfacial bond strength and, consequently, the position of the shear-failure plane. When cement is placed against filter cake, a gas flow path can form at formation interface (Ladva et al., 2005).

Centralization is another important consideration. Incorrect placement or incorrect number of centralizers may inhibit cement placement in the narrow annuli between pipe and the wellbore as the pipe and wellbore are not concentric. It may also adversely impact flow regimes. Ultimately, a decentralized casing may lead to creation of flowpaths in the cement and/or loss of cement integrity.

Other downhole factors of importance include wellbore inclination and geometry, casing geometry and integrity parameters (yield/collapse), and expected cyclical loading/unloading of casing/cement (stress level frequency and intensity). Additionally, fracture gradients, formation pressures and downhole temperatures, and drilling history (including influx and lost circulation incidents) are critical parameters.

Cyclic Stress Loading and Unloading on Cement

The most common comments about cement failure in the literature were related to cement flexibility and its resistance to continued stress loading and unloading as the major factor in cement failure. Conventional cement may fail after just two to three cycles of significant stress loading and unloading due to stimulation, production start up or shutdown, or a number of other activities. More flexible cement, such as foamed cement, is more elastic and, therefore, able to with stand repeated stress cycles without failure. For applications wherein the well will experience multiple stress cycles throughout its lifetime, more flexible cement is preferable.

5. CONCLUSIONS

The safe construction and maintenance of deep offshore oil and gas wells requires a scientific understanding and assessment of the wellbore materials used and their interaction with the wellbore environment. The stability of wellbore cement is of extreme importance to the safe construction of wells for deep oil and gas production. Cement is a critical aspect of well control in that it provides both zonal isolation and casing support. Zonal isolation is critical in order to exclude fluids (water, gas) in one zone from oil in another zone. The cement also minimizes casing buckling, parting, and elongation caused by stresses in the wellbore environment. A good cement job is needed to reach the full producing potential of the well.

This report highlights topics of further research and technology development interest pertaining to cement design, placement, and long-term integrity based on a review of our current state of knowledge. Industry experts and literature reviews focused on key research needs including monitoring cement post-placement, understanding cement stability under relevant wellbore conditions, understanding cement quality control, determining the impact of frequent stress loading and unloading events, and addressed the lack of industry standard calculations to determine cement characteristics and properties. These considerations must be addressed in any successful cementing program.

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