

Increasing ROI by engineering cement sheaths

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Abstract

Oil and gas producers are seeing increased pressure from stakeholders to demonstrate top tier peer performance in the areas of environmental safety and return on investments (ROI). Today many governments are using historical performance in the areas of well safety and environmental adherence in their leaseholder selection process. Additionally many investors use business models that include not only assets, equities, liabilities and return on investments (ROI), but also include safety performance and environmental stewardship. A cement sheath engineered to provide complete zonal isolation for the life of the well is a major contributor to reducing the well's environmental risk profile and increasing its ROI.

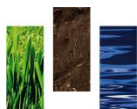
Background

Many of today's large reservoirs are not only technically challenging (ultra-deep water, high pressure and/or high temperature, sub-salt) but are located in remote areas. Well construction and completion cost for these wells can easily exceed 1 million dollars per day. Increasing their Return on Investment (ROI) requires to efficiently decrease non productive times (NPT) and shorten the operations. In terms of cementing operation, this translates into ensuring cement placement is performed as designed, reducing the waiting on cement (WOC) time, and achieving complete zonal isolation.

Conversely, well construction for shale gas and shale oil reservoirs may not be as technically challenging but are typically located in areas easily accessible by the public. In addition most shale wells require massive fracture stimulation treatments, (\$2-4 million) to achieve the well's productivity targets. In either case the cost to drill and complete these wells is a sizable capital investment, and exposure to environmental problems is always present.

Today more than ever the old adage "you only have one chance to drill and complete a well correctly" has never been more true. A properly constructed well is one that provides the safe and efficient delivery of hydrocarbons and does not require costly work-over programs. One of the most critical well activities in achieving a properly constructed well is cementing.

A successful primary cement job is one that provides not only pressure control and casing stability during well construction but also delivers zonal isolation during the entire life of the well. However loss of zonal isolation due to cement sheath failure can result in well problems associated with sustained casing pressure, loss of reserves due to inter-zonal fluid flow and in extreme cases loss of casing integrity (Figure 1). Reestablishing zonal isolation due to cement sheath failure is technically and operationally challenging and usually requires expensive work over programs.





Towards new technologies

Over the past 30 years the oil and gas producers and cement service companies have dedicated millions of dollars in R&D to the study of zonal isolation. Many of these studies have focused on the areas of cement placement, cement hydration, fluid flow prevention, cement sheath failure and repair of failed cement sheaths.

These studies indicated that, depending on the type of well, simply designing a primary cement job to achieve the required cement height, complete wellbore placement and preventing fluid flow may not be sufficient to maintaining zonal isolations for the life of the well. R&D studies in the area of cement sheath failure repair have shown that repair of a micro-annuli or a failed cement sheath is not only technically challenging, but also very expensive.

Additionally, these studies have led to changes in cement sheath design philosophies, and led to the development of higher order design tools such as cement mechanical integrity (CMI) and computational fluid design (CFD) simulators and the introduction of cement mechanical property modifiers.

Towards multi-disciplined, multi-staged, workflow

Changes in primary cement design philosophies have led to the use of multi-disciplined collaborative well teams. These teams are typically created during the planning stage of the project, and are composed of not only well construction and cement service company engineers but include the project's completion and production engineers. This team approach enables the cement design engineer to include all of the well's lifecycle events in the cement design (Figure 1).

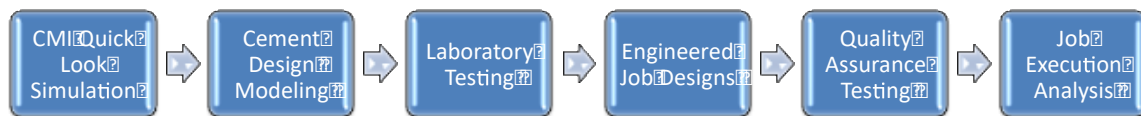


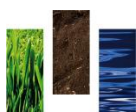
Figure 1. Workflow for ensuring cement sheath integrity

First phase

During the well planning stage, Cement Integrity Quick Look simulators enable the operator's wells team and cement service provider to quickly determine the risk of cement sheath failure for conventional and advanced cement designs. Quick Look simulators help the wells team to identify what are the well events that create the highest risk for cement sheath failure and how do well design changes affect the cement failure risk profile. Additionally Quick Look simulators help the cement design engineer identify which advanced Cement Integrity Model to use, thereby increasing cement design accuracy and reducing design time and laboratory testing.

Second phase

The cement design engineer uses hydraulic and CFD simulators to determine casing centralizing, cement placement, cement volumes, wellbore pressures, potential for channeling, slurry design temperatures, and the potential for post-placement fluid flow (Figure 2). He also uses a CMI simulator to identify how the cement design will perform during the life of the well (Figure 3). Analysis of the CMI simulations enables him to determine the probability of cement sheath failure, pinpoint the mode(s) of failure (micro-annuli, shear damage, tensile cracking or diskings) and identify the required mechanical properties, (Young's Modulus, Poisson's Ratio, Tensile Strength, Cohesion and Friction Angle) to prevent cement sheath failure.



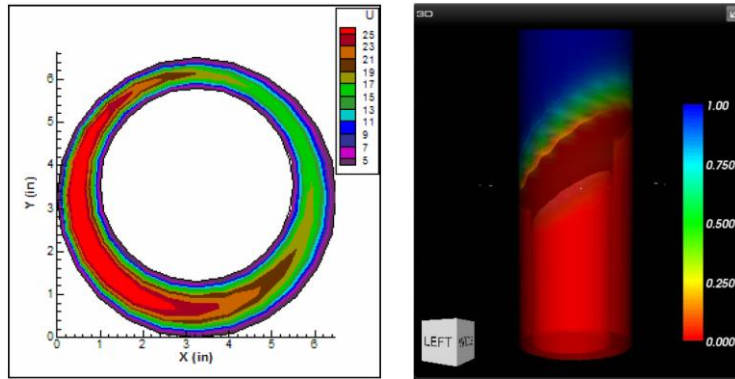
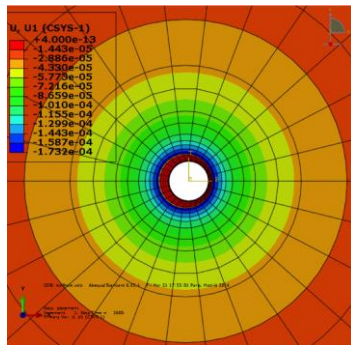
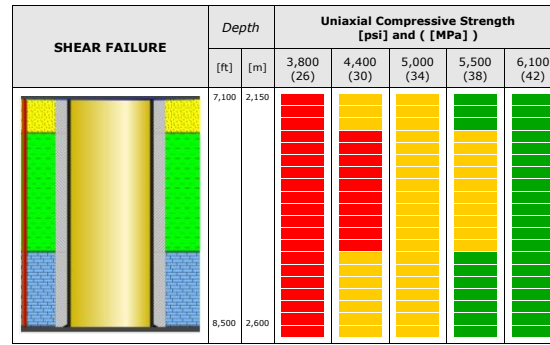


Figure 2. Examples of CFD annular fluid flow charts (from Savery et al., 2008)



CurisIntegrity CI-N numerical simulator

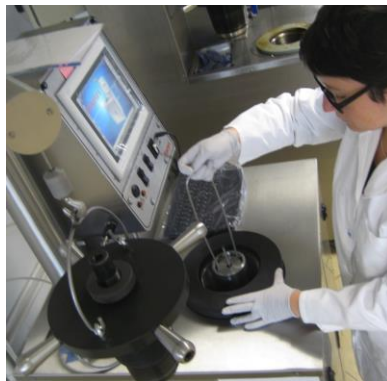


CurisIntegrity CI-A analytical simulator

Figure 3. Examples of CMI charts

Third phase

The cement design engineer reviews the design simulations with the well team, and the team selects the cement performance windows. Then, the cement design engineer uses a cement laboratory to design and test the cement slurry. In addition to the customary cement design tests, (total thickening time, fluids loss, free fluid, compressive and gel strengths testing), the cement design’s mechanical properties are measured using a triaxial load cell (Figure 4).

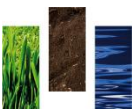


Conventional cement testing



Mechanical properties testing

Figure 4. Testing in laboratory



Fourth phase

The cement design engineer re-runs CMI simulations using the triaxial mechanical properties measured in the laboratory and determines if the cement design will maintain zonal isolation and where it resides within the required performance window, (safety factor). The wells team reviews the cement design and CMI simulations and decides either to approve or reject the design (Figure 5). If a redesign is needed, typically mechanical property modifiers are included in the new cement design. The new cement design(s) is then re-tested in the laboratory, and the mechanical properties are again measured using the triaxial load cell. The re-designed cement mechanical properties are inputted into the CMI simulator and the well team reviews the simulations. This iterative cement design process is continued until all the cement performance parameters are met.



5 modes of losses of cement sheath integrity

Safety analysis based on:

- 3 values for Young's modulus
- 2 values of Standoff

Green: Undamaged

Orange: Close to be damaged

Red: Damaged

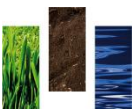
Figure 5. CurisIntegrity CI-A1 performance window and safety factor

Typically the approved mechanical integrity cement design(s) are not re-designed for each of the project's wells. However to ensure safe cement placement, the usual quality control tests, (total thickening time, free fluid, fluid loss, etc.) are performed before each cement job.

Towards increasing ROI

One may ask, why dedicate engineering resources to develop primary cement designs during the project-planning stage? The answer is simple: Through this process, the wells team can implement well design changes that can greatly reduce the risk of cement sheath failure. For example simply changing the mud weight can have a dramatic impact on the cement sheath design. Additionally the value created from these teams resides in reducing the project's financial, environmental and well safety risk profiles due to cement sheath failure.

In closing you only have one chance to cement a well right. A cement sheath designed to perform under all expected well conditions is not expensive and the value it generates is enormous. Conversely, repairing a failed cement sheath is both technically challenging, expensive and can cause problems throughout the project's life.





Conclusion

- Stakeholders have increased pressure for producers to demonstrate top tier performance in safety, environmental stewardship and ROI.
- New mega reservoir projects are technically challenging, located in high visibility areas and are capital intensive.
- You only have one chance to drill and complete a well correctly.
- Zonal isolation for the life of the well is essential to achieving top tier performance.
- R&D studies have greatly increase the industry's understanding of how cement sheath fail, and how to prevent failure.
- Repairing a failed cement sheath is very expensive and not always successful.
- New cement design tools and mechanical property modifiers have greatly increased both primary cementing success and achieving zonal isolation for the life of the well.
- Project teams are essential in developing primary cementing systems that will perform for the life of the well
- Mechanical property laboratory testing is essential in cement sheath designs.
- Zonal isolation for the life of the well enables faster reservoir harvesting, lower lifecycle cost and increased return on investments.

