

## Cement Sheath Must Endure Long Term

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HOUSTON—Zonal isolation in well cementing is critical to the long-term success of any oil or gas well. Without proper zonal isolation, gas migration, and subsequently, sustained casing pressure may result.

Several factors are important to ensure proper zonal isolation in any drilling and completion campaign. These factors, which ultimately determine the cost effectiveness of the oil/gas well program, include drilling practices, cement type and composition, mud removal, and cement placement techniques.

This article focuses on cement sheath durability and its role in reducing gas migration for the life of the well, specifically in the Marcellus Shale play. Gas migration can occur at any point during a well's lifetime. However, the risks and mechanisms of migration can be divided into two periods: short and long term.

Short-term gas migration is the period from the time a cement job begins until the cement is finally set. This is no more than a few hours, during which gas migration may occur as a result of several cement parameters, all of which relate to maintaining adequate hydrostatic pressure and preventing gas from entering the cement matrix.

The cement must maintain enough hydrostatic pressure during placement and initial setup to combat any fluids or gases moving from the formation to the surface. This is controlled through adequate slurry density; good fluid loss control; various gas control additives; and quick liquid-to-gel transition time, once the cement has been placed.

Long-term gas migration is the period starting when cement sets through the end of the well's lifetime. Gas migration during this period can occur in as little as a week and as late as several years after cementing.

Once the cement is set, there are many variables in the environment, in well operations, or even in the properties of the cement itself that can contribute to gas migration. Many cementing companies are addressing short-term gas migration already. However, the detailed study of long-term zonal isolation is limited. This article will highlight the causes of gas migration in the long term, as well as

some important aspects of cement design and placement that can help prevent zonal isolation issues.

### Damaging Forces

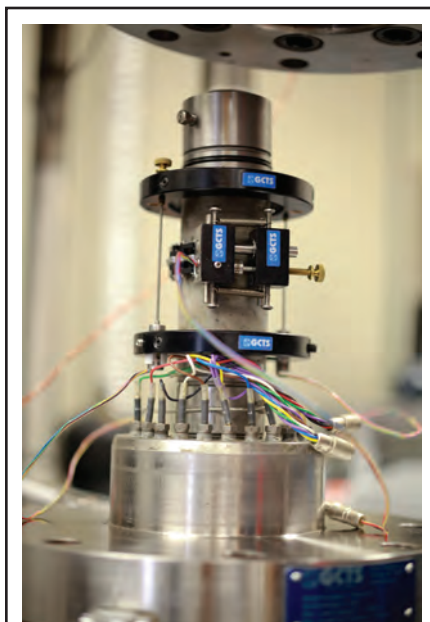
Drilling a natural gas well in the Marcellus play can take up to four weeks. After setting the conductor, the next string to be cemented is the surface pipe. After two to three days of drilling, the intermediate casing is set at around 2,000 feet. Then, after a standard wait on cement of eight hours, well operations commence drilling to the production zone. This lasts another two to three weeks.

During that period, the cement sheath between the intermediate and surface casing is exposed to daily well-construction-related stresses. Drilling involves changes in pressure, bit trips, and vibration. These stresses are cyclic and have the potential to damage the cement sheath, which must maintain an adequate seal in critical areas of the well to control any potential gas or fluid flow.

Hydraulic fracturing is another operation that may affect the cement sheath, especially in the production string. Casing will expand as it is pressured, applying tension to the cement sheath. Typically, a hydraulic fracturing operation occurs in several stages, which causes this stress to cycle between high and low pressure.

This type of operation may cause the cement sheath to de-bond from the casing, or stress the cement sheath to the point of cracking. Such failures could cause gas migration through the cracked cement matrix, resulting in sustained casing pressure.

Another cause for failure is in the downhole environment surrounding the cement sheath. Chemical attack is very



To ensure long-term zonal isolation, it is important to test and optimize cement's mechanical properties, which include Young's modulus, Poisson's ratio, tensile strength and anelastic strain.



detrimental to a cement system, and degrades the cement matrix, causing increased permeability and decreased compressive strength and overall integrity. Eventually, this will cause gas migration through the cement matrix, resulting in sustained casing pressure at the surface.

There are many cement additives that can reduce or eliminate the effects of certain chemical attacks. If cement sheath failure and gas migration are linked to chemical attack, these additives can be very useful in preventing sustained casing pressure.

## Cement Placement

Prior to cementing an intermediate casing in the Marcellus play, there usually is a water-based mud in the well. Drilling fluids are necessary to lubricate the drill bit, transport cuttings and maintain wellbore stability. However, in cementing, mud is just in the way.

Mud removal is very important to the long-term prevention of gas migration. Any mud left in the wellbore or on the casing could potentially result in a poor cement bond. However, if a channel of mud remains in the wellbore, it will dry eventually, leaving a channel in the cement that will allow formation fluids or gas to flow through.

Good mud removal can be achieved by following these guidelines:

- Ensure the mud is adequately conditioned prior to cementing.
- Design an optimized spacer and ensure enough volume is used.
- Centralize the casing.
- Rotate and reciprocate the casing while pumping, if possible.
- Pump at an adequate rate to ensure optimal fluid movement.

In addition to these guidelines, maintaining the designed density of the cement while pumping is critical. Cement pumped at the designed density has cement, water and additives in the correct ratios, which provides adequate fluid-loss control, enough available pump time, and good compressive strength development.

Cement pumped above or below that designed density will have properties different from original design expectations, potentially resulting in a poor quality cement sheath. Preventing gas migration lies in controlling the cement properties before and after setting.

## Cement Properties

Cement systems typically are tested while liquid for specific properties and initial compression strength development. These tests are run in field laboratories all over the world for the hundreds of cement jobs run daily. Standard cement properties include thickening time, compressive strength development, rheology,

fluid loss, and free fluid.

These properties indicate whether a cement system can be pumped and for how long. They also indicate the stability of the system and its ability to develop compressive strength.

These properties also can be used in conjunction with testing for short-term gas migration to determine whether a system is likely to allow gas flow while the cement is still liquid. However, none of these properties indicate whether long-term gas migration can be an issue.

Outside of compressive strength, cement systems rarely are tested for these properties after the cement has set. Yet, these tests can indicate the ability of a cement to maintain zonal isolation during the life of the well, and indicate any potential for long-term gas migration. Increasing a cement's ability to handle stresses is very important.

To achieve this, the cement's mechanical properties need to be optimized. These include Young's modulus, Poisson's ratio, tensile strength, and anelastic strain.

Young's modulus is a measure of how stiff a material is. The larger the number, the stiffer the material. The typical range for cement is 140,000 to 1.4 million psi. For cement to perform well, this number must be optimized. If it is too low, the cement may be of poor quality; if it is too high, the cement becomes too brittle.

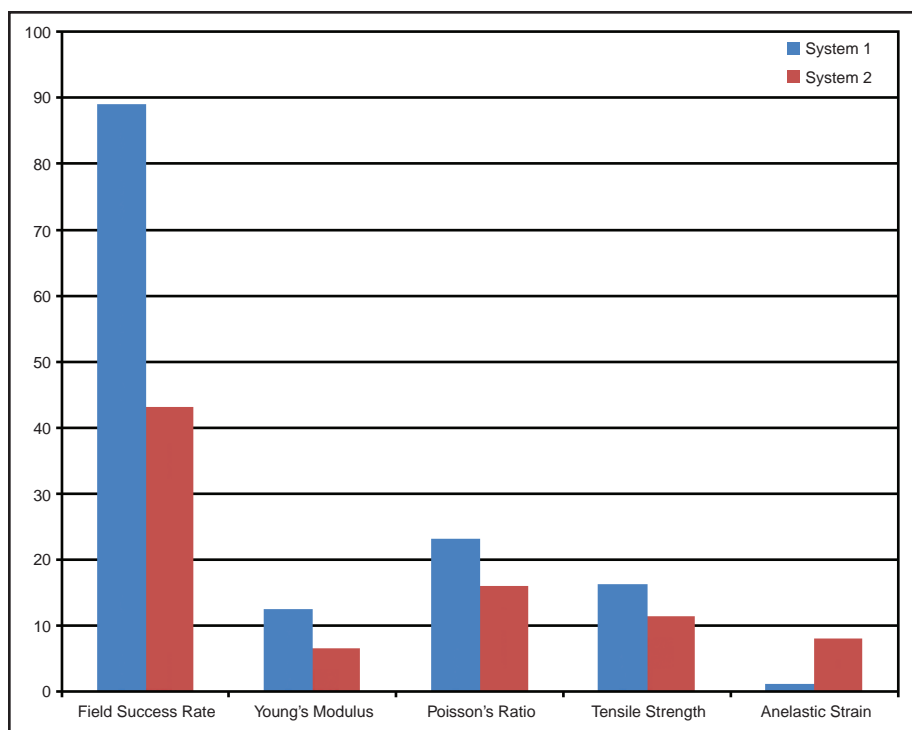
Poisson's ratio is another value that when optimized can help increase the cement sheath's resistance to failure. As a cement specimen is stressed axially, it will deform both axially and radially. The ratio of the deformation is Poisson's ratio. A higher Poisson's ratio means the material can withstand greater deformation before failure. This is a desirable trait in a cement system exposed to stress.

## Cement Sheath Stresses

Cement systems have the ability to perform very well in compression. However, in practice, cement sheaths are exposed to other forces, including tension. Any time pressure is applied to the casing and it expands, the cement is being pulled in tension. Cement systems have a relatively low tensile strength, compared with other materials such as steel casing. However, cement can show improved tensile strength through design changes and including certain additives.

The different stresses cement sheaths are exposed to in the wellbore are often

FIGURE 1



cyclic forces. A material usually can maintain its integrity when exposed to a small force one time. However, when exposed to this same force many times over a long period, such as during drilling or hydraulic fracturing, the cement sheath's integrity may become compromised.

This scenario is simulated during the anelastic strain test, which uses a compressive load cycling between a low and high force compressing the cement sample. Sample deformation is measured over time, resulting in a curve showing the percentage of deformation versus time or cycles.

The smaller the anelastic strain number, the higher performing the cement sheath is. This information will enable the engineers designing a cement job to select a system that shows the most recovery and least total deformation.

These properties can all be correlated to determine the ability of a cement to withstand outside forces. As the integrity of the cement increases, the cement sheath will be able to maintain complete zonal isolation while enduring cyclic stresses from drilling, fracturing, and other sources.

### Marcellus Case History

Cementing operations in the Marcellus Shale involve several slurry designs. The success of the cement job depends on cement design, type, composition, and cementing program.

Two cement slurry systems were placed in intermediate casing strings in several wells in the Marcellus Shale. One system was almost twice as successful as the other, which led to an investigation\* to determine the source of success so that other cement systems could be improved.

Short-term gas migration analysis indicated successful results for both systems and gave credence to the idea that the failures were the result of long-term gas migration factors such as cement durability.

As a result, testing to determine the possibility of long-term gas migration was inevitable. To validate the hypothesis that stresses on the casing resulted in weakening the cement bond in the intermediate casing, tests were conducted for mechanical properties, tensile strength, anelastic strain, impact resistance, and seal durability.

Basic cement testing—thickening time, compressive strength, fluid loss, free fluid and rheology tests—conducted on both system 1 and 2 showed few differences. These variations were not significant enough to account for the dissimilarity in cement durability.

An analysis of set cement properties further strengthened the argument that

cement design and composition were the reason for the difference in field results. The differences in compressive strength between the two systems were too low to be considered significant. This led to in-depth testing of mechanical properties for Young's modulus, Poisson's ratio, tensile strength, and anelastic strain.

Figure 1 shows the comparison of each of the mechanical properties with the field results. Young's modulus, Poisson's ratio, and tensile strength were all higher for system 1. However, as seen in Figures 2A and 2B, anelastic strain potential calculated from the slope of deformation versus cyclic loads was lower for system 1, resulting in less deformation

FIGURE 2A

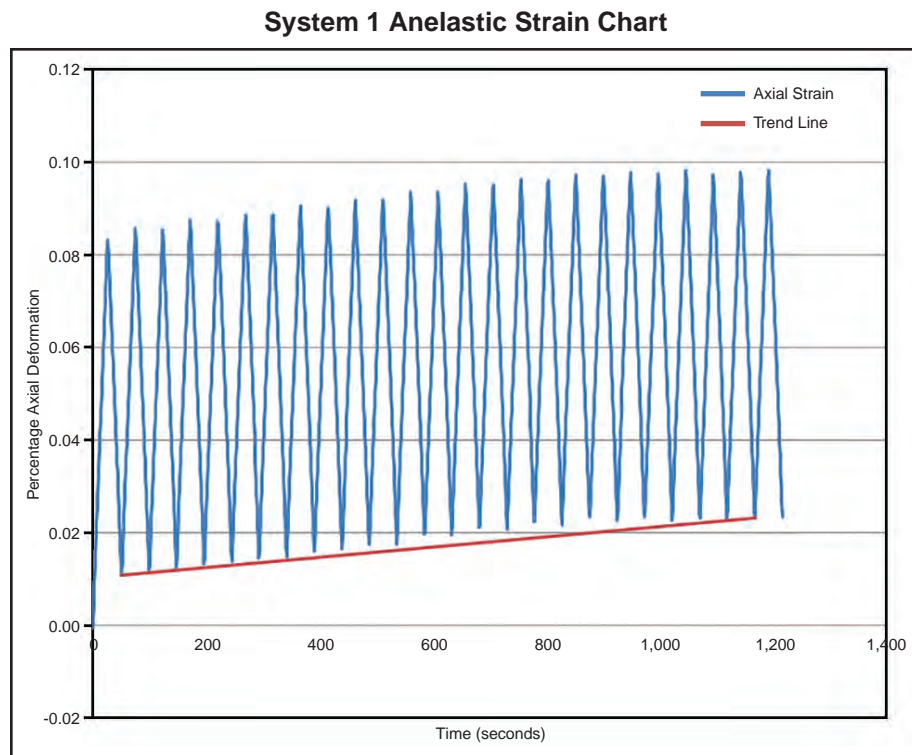
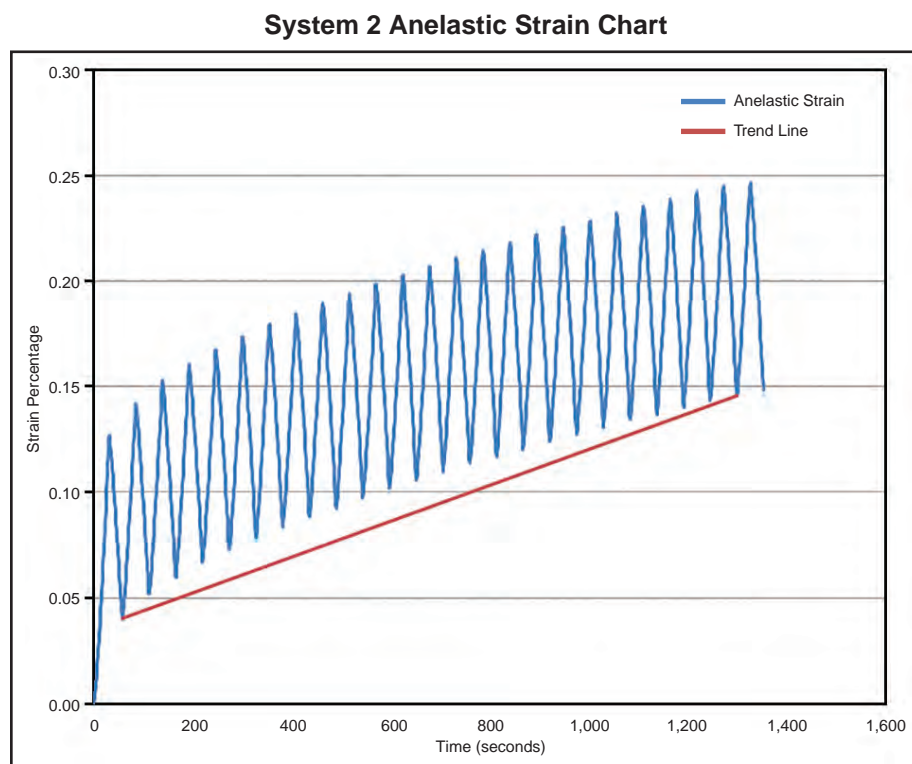


FIGURE 2B







in the cement sample. Consistently better mechanical properties, along with the higher field performance of system 1, may be linked to the durability of the cement system.

## Conclusions

All forces exerted on the cement sheath for the life of the well need to be considered when cementing a well. These forces do change over time, varying with the well operations as well as chemical and geologic activity. This includes the cement sheath's short- and long-term performance.

While many companies address short-term gas migration when designing their cement systems, the mechanical properties of the cement that affect long-term performance may not be a priority. When taking long-term performance properties into account results in a better cement sheath, the risk of gas migration decreases.

There are three major points to remember when attempting to prevent long-term gas migration:

- Numerous forces may be placed on

the cement sheath, and all should be considered when designing a cement system.

- Optimized cement placement and mud removal will help to prevent channeling and promote cement bonding.

- An appropriate cement design considers mechanical properties that affect long-term performance, and not only set time and compressive strength.

By designing cement for the life of a well, durability and dependability will increase, resulting in a quality cement bond even in the face of damaging forces. □

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