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Zonal Isolation Critical In Developing Unconventional Resources

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HOUSTON–The Marcellus Shale is one of the richest shale plays in the United States, stretching from upstate New York south through Pennsylvania, and from West Virginia as far west as parts of Ohio.

One important aspect of environmentally friendly development of the Marcellus is effective zonal isolation. Properly isolated wellbores provide adequate protection to the upper formations and can result in overall improved production.

These and other benefits of effective zonal isolation are reason to focus on improving and optimizing the cementing systems used in each well. Properly designed and executed cement jobs are the key to continuous and profitable operations in the Marcellus Shale.

Horizontal drilling and hydraulic fracturing have played key roles in stimulating production from formations with low productivity, allowing oil and gas production to be initiated in low-permeability oil and gas formations. Applying hydraulic fracturing to producing natural gas from coal beds, tight gas sands, and unconventional shale formations has resulted in the marked expansion of estimated U.S. natural gas reserves.

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Zonal Isolation

Successfully designing and implementing multistage hydraulic fractures in low-permeability shale reservoirs requires being able to reliably predict flow rates. Although there are sophisticated models for predicting flow rates from multifractured horizontal wells in shale reservoirs, none of them is applicable if cement integrity is not maintained.

Hydrocarbon movement changes the pore pressure in a reservoir, which results in effective and total stress changing as a result of poro-elastic effects, as evidenced by seismic events and reservoir compaction. Imprecise prediction of the reservoir stress path (i.e., a change in in-situ horizontal stresses with pore pressure) could affect wellbore failures.

The primary purpose of cementing is to ensure proper zonal isolation. Zonal isolation protects groundwater aquifers, and isolates producing and nonproducing zones for optimal production.

Many techniques have been used to improve zonal isolation. These include multiple scratchers and centralizers, improving mixing systems, altering flow rates, stage systems, high early-gel-strength cements, and additives for fluid loss control. Despite these, costly remedial cementing operations are needed occasionally to correct zonal isolation problems.

A typical Marcellus Shale well will be drilled vertically to 6,500-7,500 feet. About 2,000 feet of this vertical section will be cased and cemented before the operator drills horizontally into the pay zone, reaching out as much as 13,000 feet measured depth. Several best practices for vertical cementing must be modified to ensure a successful cement job in a horizontal well. This makes horizontal shale well cementing highly technical, requiring specific engineered cement properties and operational practices to meet the demands of these wells.

In many shale plays, operators prefer a "manufacturing" style of drilling, using the same formulas and processes on each well in an area. This reduces cost and time when drilling for shale gas.

However, this technique can lead to improperly designed slurries and overlooking key parameters when wells are not properly planned, designed and managed. With the emphasis on zonal isolation and wellbore integrity, improving the success of cementing represents a potential for major cost reductions and increased environmental safety.

Sustained Casing Pressure

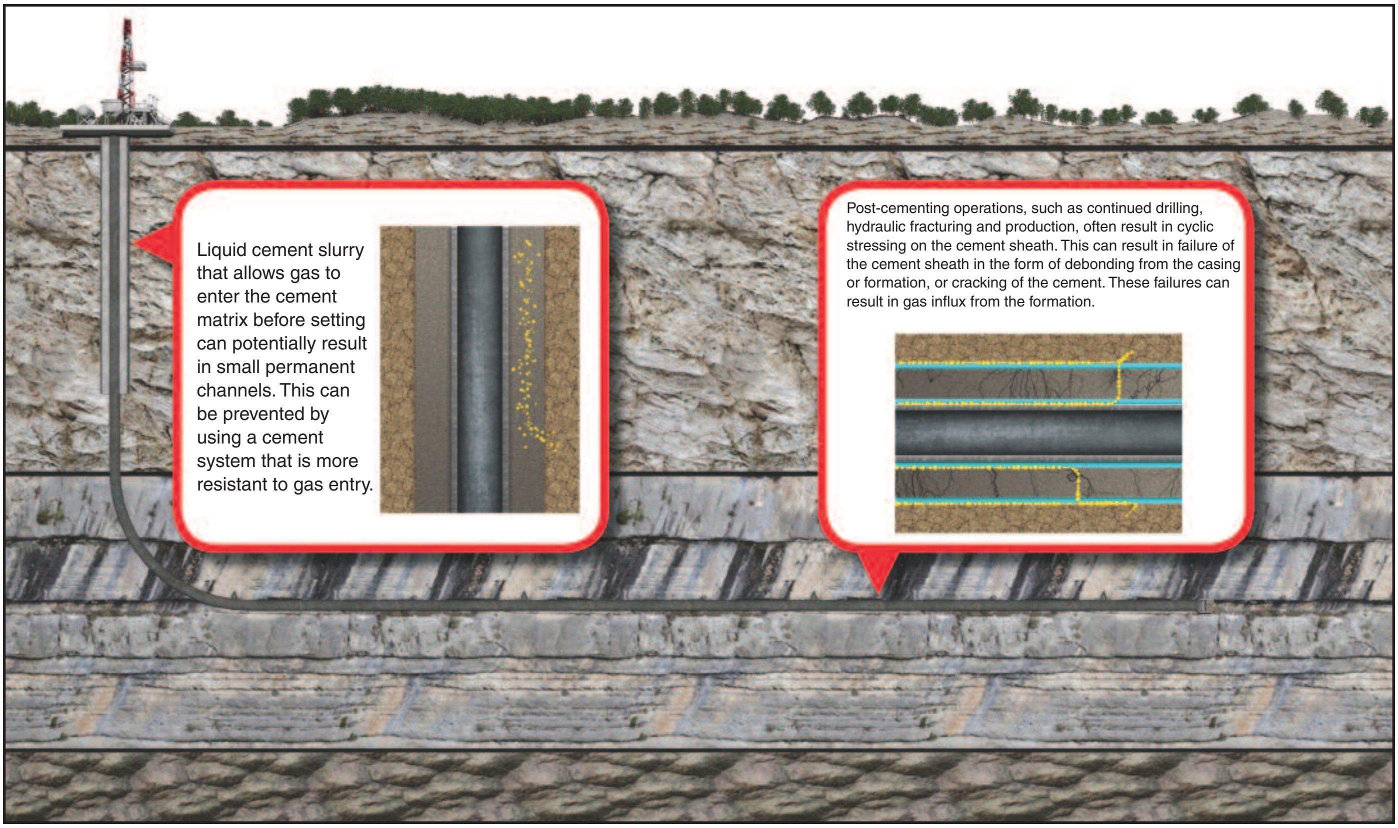
Sustained casing pressure (SCP) is a possible symptom of improperly placed cement or cement that is not durable. If the casing string is cemented properly, surface pressure gauges on the casing annulus should read zero psi. A small amount of pressure can be created by thermal expansion of fluids, but once that pressure has been bled off, the pressure on the casing annulus should remain at zero.

If the pressure returns after the well has been bled down, the well is said to exhibit SCP. This could be the result of the cement slurry not having been placed in the entire annulus and/or the inability of the cement sheath to withstand stresses from well operations.

Depending on when it occurs, SCP may be related to any of sev-

FIGURE 1

Gas Migration and Cement Failure



Liquid cement slurry that allows gas to enter the cement matrix before setting can potentially result in small permanent channels. This can be prevented by using a cement system that is more resistant to gas entry.

Post-cementing operations, such as continued drilling, hydraulic fracturing and production, often result in cyclic stressing on the cement sheath. This can result in failure of the cement sheath in the form of debonding from the casing or formation, or cracking of the cement. These failures can result in gas influx from the formation.

TABLE 1

Wellbore Integrity Before and After Production

Preproduction	Formation damage during drilling (caving)	
	Casing centralization (incomplete cementing)	
	Inadequate drilling mud removal	
	Incomplete cement placement	
	Inadequate cement/formation bond	
	Inadequate cement/casing bond	
	Cement shrinkage	
	Contamination of cement by mud or formation fluids	
Production	Mechanical stress/strain	Micro-annulus at casing/cement interface
		Disruption of formation cement bond
		Fracture formation within cement
	Geomechanical attack	Corrosion of casing
		Degradation of casing (carbonation, sulfate and acid attack)

eral causes of gas migration. Short-term gas migration occurs in the period between the cement slurry being placed and the cement setting, which usually occurs within hours. During this period, gas has the opportunity to enter the cement slurry and progress upward, creating small channels that remain after the cement has set.

Several cement systems, such as thixotropic cement, have been developed to prevent short-term migration. These systems transition very rapidly from liquid to gel. Once the cement has gained a significant amount of gel strength, the gel will keep formation gas from migrating through the cement matrix.

Other cementing additives have been developed to prevent migrating gas from entering the cement slurry while it is setting. Figure 1 depicts some of the ways that gas migration can cause cement failure in a well.

Long-Term Gas Migration

Long-term gas migration typically occurs weeks to months after the cement has been placed. This usually is the result of a micro-annulus or crack in the cement sheath. These failures in the cement sheath will occur when the cement has been exposed to some sort of stress.

Typically, stress is cyclic and can come in the form of impact from post-placement drilling operations, casing expansion caused by fracturing operations, fluctuating temperature and pressure caused by production, and geomechanical stresses.

These types of cement failure can be mitigated by using more durable cement. Durable cements may be able to hold up to the long-term stresses the cement sheath will encounter over the life of the well.

Table 1 lists the wellbore integrity issues that may occur during the life of a well. As shown in blue, most of the issues are related to either the quality of the cement or the cement's behavior under downhole conditions. Proper laboratory tests, engineering analysis, and field observations can be the key to overcoming such issues.

In a project intended to develop an integrated process to optimize zonal isolation, cement systems used in the Marcellus Shale were observed in the laboratory and the field. Lab and field data shed light on the characteristics of the cement systems in place.

The study focused on all casing strings in the Marcellus play, and analyzed historical data for areas of improvement. It also included collecting field samples and performing a series of standard cement tests.

Specialized testing, such as fluid migration analysis, annular seal durability, shrinkage of the cement sheath, and analyzing static gel strength, was conducted. Test results were compared with data seen in the field from cement bond logs and field reports.

This holistic approach helped develop a strategy to identify solutions in areas, and thus secure an environmentally friendly operation for developing the Marcellus or any other shale play. This information shows how focusing on cement system design can enable more effective zonal isolation in the Marcellus Shale.

Short-Term Migration

Short-term gas migration was one area investigated during this project. This cement property can be tested in the laboratory using a fluid migration analyzer, which simulates formation pressure by applying nitrogen gas pressure to a cement column. Figures 2 and 3 show two scenarios of fluid migration analyzer tests.

Figure 2 shows a cement system that is well designed to prevent gas from entering the cement slurry (note that the total

FIGURE 2

Slurry Resisting Gas Entry

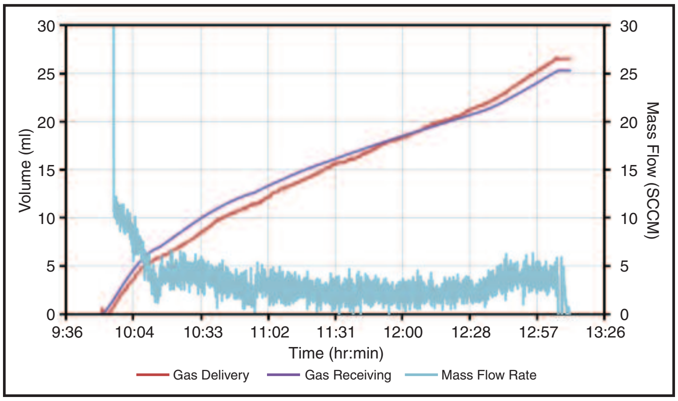
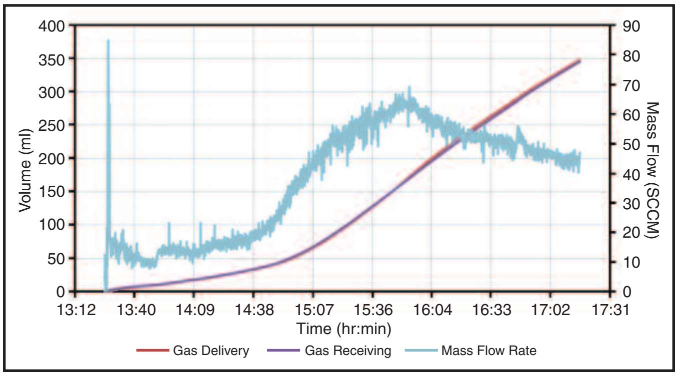


FIGURE 3

Slurry Allowing Gas Entry



volume of gas entering the slurry never rises above 30 milliliters). This cement system is thixotropic, which develops gel strength very rapidly and helps prevent the influx of gas from the formation.

The system used in Figure 3 is a more conventional system that takes much longer to develop gel strength. This system allows nearly 350 milliliters of volume to move through the slurry column.

Another area investigated that may contribute to preventing gas migration was controlling fluid loss. Fluid loss control is very important when designing a cement system to resist gas migration. As fluid is lost from the cement slurry to the formation, a loss of hydrostatic pressure may occur.

Hydrostatic pressure is vital for preventing gas migration in the early stages of cementing. Adequate fluid loss properties in the cement system will better prevent gas migration. ❒

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