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Gas Well Integrity and Associated Gas Migration Investigations in the Marcellus Shale

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Abstract

The Marcellus Shale is one of the largest natural gas fields in the world and has been the site of a massive natural gas development effort involving hundreds of oil and gas companies. With the onslaught of the "shale revolution," developers moved into states like Pennsylvania and began drilling/completing natural gas wells by the hundreds. This development occurred so rapidly that attention to issues such as wellbore natural gas intrusion was not initially given the priority it demanded in all cases. This led to instances of alleged natural gas migration and impacts to groundwater supplies in several areas of the region. Although there has been an onslaught of evaluations geared toward the study of groundwater contamination, the author has researched the natural gas wells themselves. Based on thousands of wellbore integrity studies in the Marcellus and other worldwide shale regions, this paper will summarize the forensic processes, analysis methods, and approaches used in assessing wellbore integrity as part of a natural gas migration investigation. The paper will also present details that pertain to remedial alternatives and approaches to wells requiring attention.

Keywords

Natural gas migration, wellbore natural gas intrusion, well integrity, annular pressure, shut-in pressure test, venting rate test, temperature/audio log, remedial cement squeeze

Introduction

Oil and natural gas development in the Appalachian Basin area began in 1859 with the discovery of oil in the Drake Well in Titusville, PA (Owen and Dott 1975). The Marcellus Shale is a Middle Devonian-age black shale that occurs at depths ranging between 4,000 and 8,500 feet in portions of Maryland, New York, Ohio, Pennsylvania, and West Virginia (Grant 2010). Initial unconventional development of the Marcellus Shale began in 2004 with Range Resources drilling and completing the first Marcellus horizontal well in Washington County, PA (Ventura 2013). Since 2008, Pennsylvania's natural gas production from the Marcellus Shale has increased exponentially as a result of the utilization of the unconventional drilling and completion techniques developed within the Barnett Shale in Texas (PA DEP 2013). With the advancement of this drilling and completion technology, the new shale plays (like the Marcellus) are now able to be commercially developed.

Consequently, with the rapid influx of new development of the Marcellus came an increase in alleged incidents of gas migration and groundwater contamination. State regulatory agencies and the oil and gas industry have continued to work together to address defective cementing and well integrity issues through aggressive remedial or other alternative actions to ensure regulatory compliance. Through involvement in these efforts and the completion of thousands of wellbore integrity studies, the author has developed a comprehensive methodology and forensic process for the assessment of well integrity relating to alleged gas migration incidents. The process is based on a holistic approach that does not rely on any single assessment tool but evaluates the overall well integrity through a litany of tests, methods, and analytical reviews. This holistic approach has been designed to facilitate the determination of well integrity and potential relationship with alleged gas migration incidents.

Initial Stray Natural Gas Migration Incidents

Historically, there have been stray natural gas migration incidents associated with oil and gas development in the Appalachian Basin, but neither documentation of such incidents nor regulatory authority to address them was in place until the mid-1980s — when the rise in oil and natural gas prices spurred conventional oil and gas development in the Appalachian Basin area. Perhaps the first widely publicized stray natural gas

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migration incident in the Appalachian Basin occurred in December of 2007 when an explosion occurred in a home in Bainbridge Township of Geauga County, Ohio (ODNR 2008). This incident was a result of an annular overpressurization issue associated with a conventional oil and natural gas well, which led to natural gas migration into the aquifers and a number of water wells in the area (Tomastik and Bair 2010). In the ensuing weeks after the incident, 26 residential water wells were disconnected, temporary water supplies were installed, and, by 2010, all of these residences were connected to a public water line (Bair et al. 2010).

Complaints and allegations of environmental impacts coincided with the early development of the Marcellus Shale and are still the subject of discussion, compliance actions, and litigation. Between 1987 and 2011, the Pennsylvania Department of Environmental Protection (PA DEP) investigated 119 stray natural gas incidents related to oil and gas activities, of which 16 were alleged to be related to Marcellus Shale wells, with the first alleged Marcellus Shale incident occurring in 2008 (Moody 2011). Perhaps the most widely publicized alleged stray natural gas migration incident in the United States occurred in 2009 in Dimock, PA. The documentary *Gasland*, which premiered on HBO on June 21, 2010, begins and ends in Dimock, a rural area of Susquehanna County where supposedly several dozen residential homes were impacted by stray natural gas migration into domestic water wells (Gilliland 2010). *Gasland*, which also alleges stray natural gas migration associated with unconventional shale development in Colorado, Texas, Utah, and Wyoming, drew national and worldwide attention to hydraulic fracturing, or "fracking," and unconventional shale development.

Regulatory and Industry Development to Address Stray Gas Migration

After the initial boom in Marcellus Shale development in Pennsylvania — and the alleged stray natural gas migration cases associated with this development — the oil and gas industry adapted by updating its well construction and cementing practices. Designing a well drilling plan and a casing/cementing program requires an understanding of the local geology in order to prepare proper well construction and well control measures for expected subsurface conditions. However, it can be difficult to develop a thorough understanding of the local geology in a new location where there may be few historical wells or where no wells have been drilled (GWPC and ALL 2009). Such was the case in northeastern Pennsylvania where a limited number of oil and gas wells had been drilled prior to the development of the Marcellus Shale in that area (Zampogna et al. 2012). Therefore, a conservative well design that includes multiple casing strings and cementing plans with proper cement type, additives, and placement to ensure isolation of formation gases and fluids is warranted (**Figure 1**).

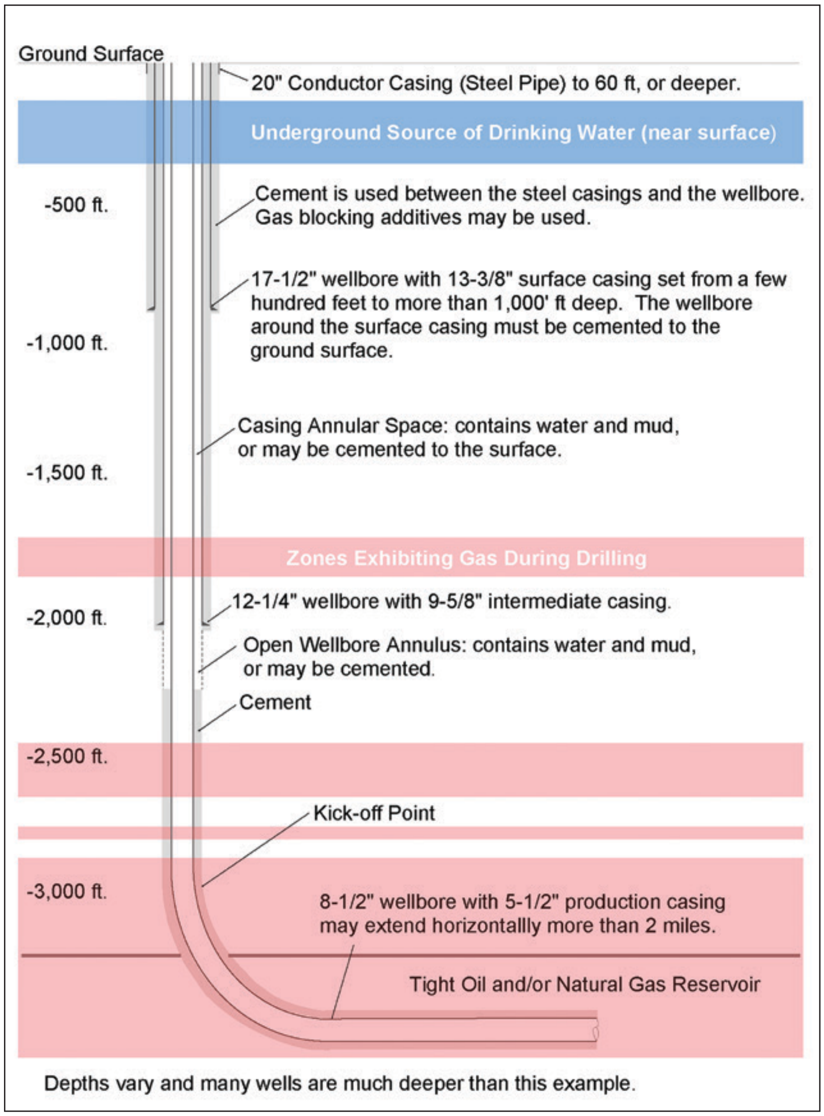

Figure 1
Sample well construction diagram.

Assessment of Well Integrity for Gas Migration Investigations

A critical component of any natural gas migration investigation is the evaluation and assessment of well integrity at adjacent oil and natural gas wells. For this paper, well integrity can simply be defined as a lack of significant leakage within the well and wellbore. Both internal integrity (e.g., casing, tubing, packers, etc.) and external integrity (e.g., cement, mud, annular fluids, etc.) must be considered and evaluated to identify potential concerns relating to the gas migration investigation that may require remedial measures.

Well integrity evaluation is based on a variety of industry standard tests and logs that have been refined for the holistic approach presented in this paper. Based on more than a thousand wellbore integrity studies, this holistic approach has been designed to facilitate the determination of well integrity and potential relationship with alleged gas migration incidents. The holistic approach does not rely on any single tool, but evaluates overall well integrity using an assortment of tests. While any one test may indicate a potential concern, the compilation of tests in the evaluation approach is intended to refine and identify evidence that the oil or gas well may be a potential source of the alleged gas migration incident. The holistic well integrity assessment process includes the following:

- Timeline analysis,
- Well casing and cementing review,
- Well logging,
- Well integrity testing,
- Geologic and gas migration pathway review, and
- Additional considerations for gas migration investigations.

Again, no single finding alone is sufficient; rather, when evaluation methods are used in concert, a proper assessment of well integrity can be made. The holistic approach and forensic processes used to assess well integrity are discussed in the following sections.

A. Timeline analysis

The initial evaluation for each well includes a review of the operator's daily drilling and well activity logs to determine where the oil or gas well was in the development process, and what, if any, activity was ongoing at the well at the time of the alleged gas migration incident. Completion of a timeline analysis is a critical step in the evaluation process to identify and evaluate potential correlations between the timing of the alleged gas migration incident and activity at the oil or gas well (e.g., drilling, completion, workover, etc.).

B. Well casing and cementing review

Review of the operators' drilling and well completion activities, including well casing and cementing records, is vital for assessing well integrity and related wellbore gas intrusion (Arthur et al. 2012). Records provided by the operator include:

- Cementing details, including: cement slurry design, fluid density, cement additives, cement volume, etc.,
- Cement bond logs used to evaluate bonding to the casing and to the formation, and
- Formation integrity test (FIT) results and leak-off test (LOT) results, if available.

C. Well logging

Cement evaluation logs are reviewed as part of the holistic well evaluation process. These logs (e.g., cement bond logs, radial cement bond logs, segmented bond log, Ultrasonic Imager tool, etc.) are utilized to locate cemented sections in the wellbore and to evaluate the quality of the cement bonding in those zones (Bigelow 1985). Temperature and audio logs are invaluable tools in assessing wellbore methane intrusion and can be utilized to identify and characterize gas flow occurring in the wellbore.

D. Well integrity testing

Multiple internal and external well integrity testing methods, including visual inspections, infrared camera videography, methane monitoring, shut-in pressure tests, annular vent rate tests, production casing build-up/leak-off tests, pressure differential tests, and pressure trend analysis, are available to assist in the assessment of well integrity.

E. Geologic and gas migration pathway review

In any stray natural gas investigation, all potential sources of stray gas must be identified and evaluated. Initially, a thorough geologic review and evaluation of potential gas sources and migration pathways are undertaken in the gas migration investigation. If available, all open-hole geophysical logs and mud logs are evaluated with particular attention paid to the occurrence of gas shows above the intended production zone. The identification of shallow gas-bearing zones is integral to evaluating wellbore methane intrusion. Gas migrates along pressure gradients from areas of high to low pressure. Gas may move up or down an elevation gradient and can travel for long distances (up to miles away) from the source. Potential gas sources and pathways include, but are not limited to, the following:

- Shallow gas-bearing zones
- Coal seams and underground coal mines
- Legacy oil and gas wells
- Natural occurrence of gas in aquifers

F. Additional considerations for gas migration investigations

As noted, other investigations are conducted in addition to the well integrity tests performed on the oil and gas wells themselves. These other tests include sampling water wells for laboratory analyses of the presence of hydrocarbons and other geochemical parameters (including isotopic analysis). Although these other investigations are separate from the well integrity assessment, their findings can help refine the assessment of well integrity by potentially identifying or excluding potential sources of natural gas.

Advanced Well Integrity Methodology

In cases where the potential for natural gas migration or loss of well integrity are suspected, a variety of assessments are performed to characterize downhole conditions within a wellbore. These assessments include a number of tests that are critical components of the gas migration investigation and provide data to determine regulatory compliance, evaluate wellbore natural gas intrusion, and determine the efficacy of remedial efforts. Generally, these tests are repeated during the well evaluation and remediation efforts in order to establish trends and demonstrate progress.

A. Shut-in pressure build-up testing

Shut-in pressure tests are used to quantify and characterize pressure build-up rates in the annular spaces being tested. Annular pressures can be attributed to a variety of causes, including well component leaks, thermal flux upon initiation of production, shallow hydrocarbon-producing formations, and other shallow overpressure formations (API 2006). A shut-in pressure test consists of closing the valve on the annulus being tested and allowing the annular pressure to build over the duration of the test. The data recorded during the test allows for construction of a curve, which provides a graphical representation of the pressure over time. The results can then be interpreted to assess the nature of the pressure within the annulus.

1. Instrument selection

The selection of transducers with appropriate sensitivity ranges is important to ensure accuracy. To prevent damaging the transducers, the instruments must be capable of tolerating the annular pressure observed during periodic monitoring. However, the instruments should not have an upper range that far exceeds the observed annular pressure. Otherwise, accuracy may be compromised.

2. Shut-in pressure build-up analysis

Plotting multiple shut-in pressure build-up test curves from an individual annular space on a single chart allows for trend analysis to evaluate changes over time. Characteristic shut-in pressure build-up curves have been observed during the evaluation of thousands of tests. Continuous monitoring of pressure data and identification of build-up curve signatures has allowed for a more robust analysis of annular pressure (**Figure 2**).

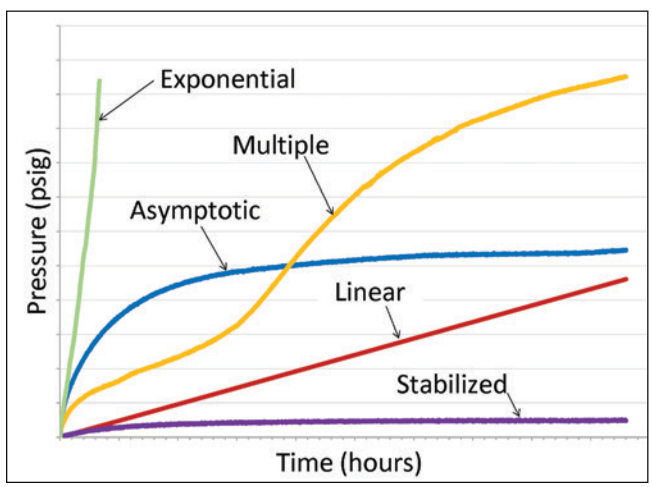

Figure 2
Signature shut-in pressure build-up curves.

While conducting shut-in pressure tests, testing errors and anomalies are sometimes encountered. Such errors can include transducer and data logger malfunctions, improperly functioning or clogged well setups, or changes in pressure due to environmental factors such as barometric pressure, surface temperatures, and internal wellbore pressures based on the fluid level in the well.

Similar to the pressure build-up signatures that have been identified, a series of signatures that identifies specific errors and anomalies based on their build-up curves has been defined by the author (**Figure 3**).

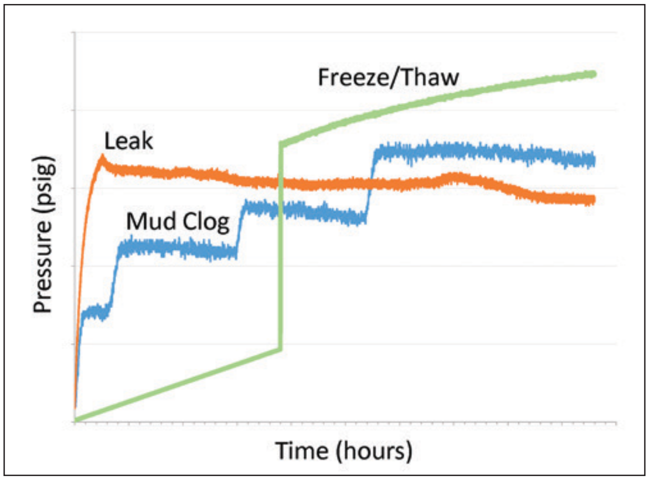

Figure 3
Signature curves of erroneous data.

The identification of these signature curves is instrumental when characterizing a well's annular pressure and confirming the quality of test results.

3. Evaluation of pressure trends

The evaluation of trends requires the repeated performance of tests over time. Shut-in pressure build-up curves can be plotted using several methods, including chronological (with a trend line or a timeline) and elapsed time. When plotting shut-in pressure build-up curves in chronological format, the x-axis is in chronological order (date and time of day). Typically, the chronological plot uses end of test data (e.g., the pressure after 72 hours from several tests). For comparative analysis, it is critical that pressures used are collected at a consistent interval (e.g., 24 hours, 48 hours, etc.). When plotting shut-in pressure build-up curves in elapsed-time format, the x-axis is in elapsed time and includes all data points from each test.

B. Vent rate testing

Vent rate tests are performed to quantify the volume of natural gas that may be present in the casing or annulus of a well. In conjunction with shut-in pressure build-up tests, they help to identify and characterize wellbore methane gas intrusion and are a key component in the assessment of well integrity.

1. Instrument selection

The orifice well tester and the critical flow prover are considered to be "primary elements" of the test assembly, and they require a method of measuring pressure on the upstream side of the flow line — the "secondary element." Due to the generally low pressures encountered at casing vents, testing is conducted using a U-tube manometer, with vent line pressure at one end and atmospheric pressure at the other. If a flow rate is less than the reportable limit for the instrument being used, qualitative testing using either a balloon test or bubble test may be conducted.

The balloon test consists of allowing a small balloon (4 to 6 inches) to inflate for 10 minutes or until the balloon is fully upright. Photographic documentation of the balloon, such as that shown in **Figure 4,** is taken at the completion of the 10-minute interval or when the balloon is determined to be inflated to an upright position. If the balloon is upright before the end of the 10 minutes, the test duration is recorded, and the condition of the balloon (minimal inflation, partial inflation, or upright inflation) is logged with the photographic documentation.

Figure 4
Photographs of different balloon test results (e.g., minimal inflation, partial inflation and upright inflation).

2. Vent rate analysis

Vent rate test results are analyzed in conjunction with other tests, specifically shut-in pressure build-up tests, to help identify and characterize wellbore natural gas intrusion. The test provides a measurement of the volume of gas that may be present in the annular spaces. Volumetric analysis of venting rates can be used to evaluate the connection between a well and the alleged natural gas migration incident.

3. Bubbling cellar assessment

Wells may exhibit "bubbling cellars" when rising gas reaches standing water in the cellar of the wellhead. Observation and measurement of the size and frequency of the bubbles may be used to estimate the relative volume of natural gas emanating from the well.

It is also useful to remove the standing water from the well cellars to screen the well using an infrared camera. Infrared video may be used to demonstrate conditions at the well to regulators. When used properly, infrared video can show whether gas is streaming at a high rate or wafting at a low rate (**Figure 5**).

C. Temperature and audio logs

Temperature and Audio (T/A) geophysical logs can be used to identify and characterize flow within a wellbore, guide remedial corrective action (if needed), and evaluate the effectiveness of the remedial corrective action after they have been completed. A discussion of individual log types is provided below with details on how the logs can be used to support the well integrity evaluation effort.

1. Audio logging

By utilizing audio logs during the well evaluation, operators can determine when flow is occurring, where the flow is originating, and where the flow is terminated. For example, if flow has been identified by increased amplitude over ambient noise originating at depths above the top of production casing cement and continuing to surface, it can be deduced that natural gas is entering the wellbore, traveling upward through the annular space and venting at the surface (**Figure 6**).

An example of greater concern would be flow identified by increased amplitude over ambient noise at depth, continuing upward, and dissipating at some depth below the base of the next outer casing string (**Figure 7**). This scenario potentially suggests that natural gas flow is entering the wellbore and exiting at some other depth. Corrective actions should generally be pursued in this scenario.

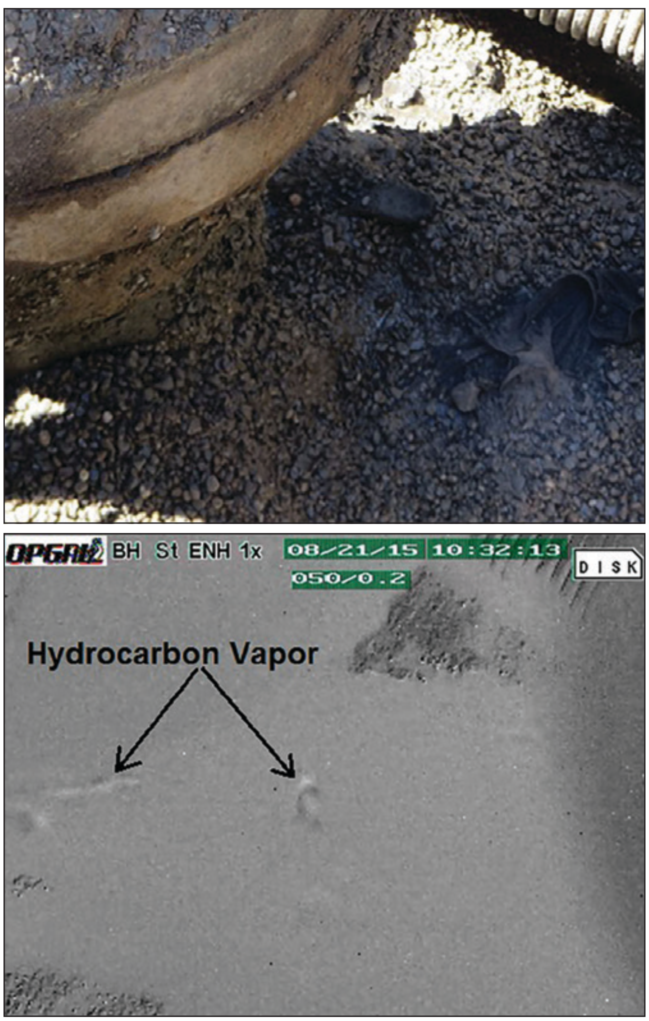

Figure 5
Photographs of a cellar in visible light (top) and in infrared (bottom).

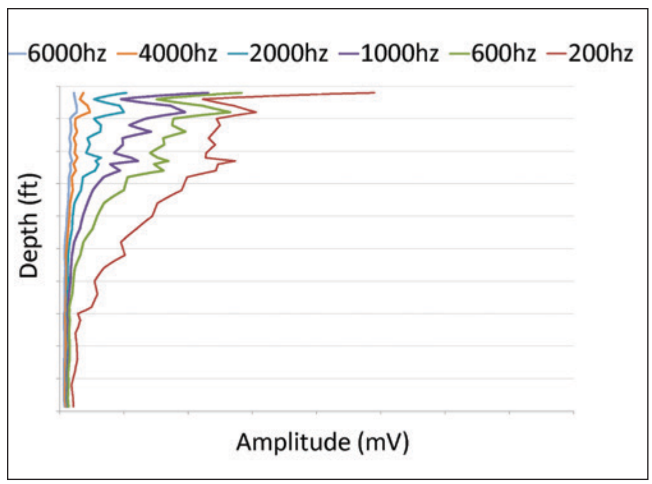

Figure 6
Sample audio log indicating venting at the surface.

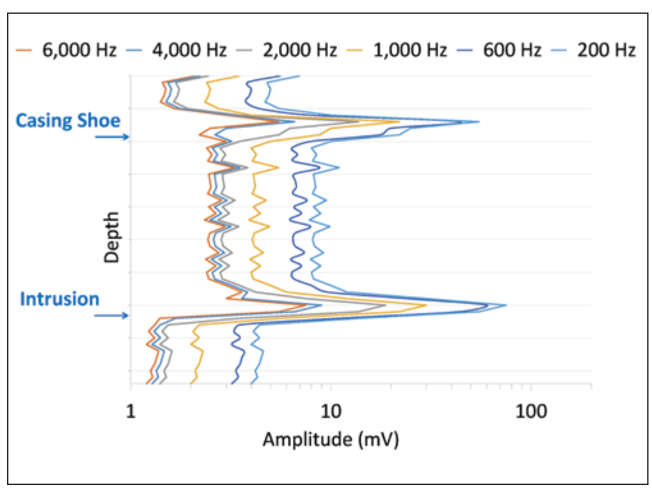

Figure 7
Example audio log indicating intrusion and shallow migration.

2. Temperature logging

The intent of conducting temperature logging is to identify depths at which deviations from the geothermal gradient occur, as deviations may indicate natural gas or fluid movement within the wellbore. These deviations are typically small, with some as little as 1°F. It should be noted that changes in the temperature gradient may also be unrelated to fluid or gas entering the wellbore. Natural variations in the static geothermal gradient may relate to lithologic changes. Geothermal gradient changes associated with lithology can be seen when logging above the Marcellus Shale. These formations consist of alternating beds of shales and sandstones with varying water retention capacities that can influence thermal conductivity. Changes in stratigraphy must be considered as an additional influence on temperature gradients and thus must be accounted for when interpreting temperature logs.

3. Quality control

The standardized logging procedures described below provide the most accurate well integrity analysis. A two-pass logging procedure, with quality control efforts, ensures the wells are prepared to be logged. It is important to ensure that noise from within the production casing is eliminated so that the analysis of the other annuli is optimized. The described T/A logging procedures establish a uniform testing protocol and a comprehensive reporting process. This process includes preparing the well, making sure the temperature passes are performed first, ensuring that the audio logs are properly reviewed for quality control and quality assurances, and analyzing any noise anomalies with greater detail. Quality assurance improvements that are implemented throughout the well evaluation process include the following:

- **Well preparation**: Prior to completing a T/A log, the well must be properly prepared in order to ensure quality of logging results. The tubing must be removed, the wellbore must be 100% filled with fluid, and the well should be allowed to stabilize for a minimum of 12 to 24 hours. The temperature log is always performed on the down-pass to ensure the logging activity has no influence on the wellbore temperature. After the temperature log is completed, fluid level is noted, and, if necessary, freshwater is added prior to completing the audio log on the up-pass.

- **Well configuration**: When running T/A logs for well integrity analysis, it is beneficial to run duplicate logs. The first pass should be done with the production casing closed and casing annuli open. The second pass should be done with the production casing open and casing annuli closed. This opposing well configuration can be used to further evaluate whether or not flow, if identified, was exiting the wellbore. The second log should be completed after allowing the well to re-stabilize and generally occurs the following day.

- **Logging practices**: Standardized logging practices ensure consistent results. The temperature log should be completed on the down-pass with a consistent speed of approximately 30 feet per minute. The audio log should be completed on the up-pass, stopping at stationary intervals approximately every 250 feet, allowing the noise to stabilize for a minute, and recording the ambient noise. Additional stationary intervals should be completed above, adjacent to, and below the intermediate casing shoe, perforations, and any anomalies identified on the temperature log.

D. Cement evaluation logs

Cement evaluation is a vital step in the assessment of well integrity for gas migration investigations. In conjunction with a review of casing and cementing details, the completion and analysis of cement evaluation logs provide insight into the presence of cement behind the casing and the level of cement bond to the casing and formation (Bigelow 1985) as well as cement integrity conditions (e.g., micro-annulus, channeling, compromised cement, etc.) (Schlumberger 1989). A variety of cement evaluation logs are available to assist with the assessment of casing and cement integrity. Select examples of cement evaluation logs are provided below.

- Cement bond log (CBL)
- Radial cement bond log (RCBL)
- Segmented bond tool (SBT)
- USI Ultrasonic Imager Tool (USIT)

Well Integrity Remediation Methods and Alternatives

If remedial action is indicated by cased-hole geophysical logging, well integrity testing, and holistic assessment, remedial action options exist. The development of these remedial methods is based on extensive research and actual field application using various procedures and products. Each remedial option has distinct advantages as well as challenges and concerns. All options should be fully evaluated when selecting the appropriate remedial method.

A. Casing perforation and squeeze remediation

A commonly utilized remedial method involves perforating the well casing and squeezing cement through the casing into the wellbore annulus. Perforations and squeeze intervals are selected based on the findings from the holistic well evaluations performed on the well. Specifically, understanding and accurately interpreting cement evaluation log(s) and T/A logs are critical for a cement squeeze to be successful. In some wells, multiple perforation intervals may be required to address wellbore natural gas intrusion adequately. When multiple perforation intervals are anticipated, the deeper intervals are squeezed first to address the potential of shallow flow being reduced by sealing off deeper natural gas flow. This methodology will also limit the occurrence of unnecessary perforations above the expected squeeze interval.

B. Alternatives to remedial methods

Alternatives to perforating and squeezing are available and should be considered when evaluating remedial options. Perforating and squeezing may not be necessary if wellbore natural gas intrusion can be controlled at the surface. Remedial alternatives can include continuous, long-term pressure monitoring, plumbing casing strings to sales lines of the production operation, and/or connecting the casing strings with annular pressure issues to a high-pressure separator with a pressure relief valve for controlled venting and blow down. Additionally, internal well integrity concerns (e.g., casing leaks) can often be controlled through the use of packers to isolate the leak and a fluid-filled tubing annulus to prevent migration of natural gas through the leak.

Sample Case History

In response to Pennsylvania landowner complaints about deleterious changes in water quality, a well integrity evaluation (following the holistic approach presented in this paper) was performed on a nearby gas well. Well integrity analysis began with preparation of the well timeline using available well records and test data. Records indicated that the construction, drilling, and completion of the subject natural gas well preceded the methane and turbidity reported in the subject water supply wells by 17 to 25 months. The subject water supply wells were within one mile of the natural gas well. Review of casing and cementing records along with analysis of cement evaluation logs for the subject gas well indicated evidence of poor cement bonding and/or a lack of apparent cement in the wellbore (behind the production casing) in excess of 1,000 feet below the intermediate casing shoe. Additionally, there was evidence of micro annuli behind the production casing, deeper in the well. Well integrity testing of the subject gas well included T/A logging, shut-in pressure build-up testing, and vent-rate flow testing. Review of integrity tests results revealed the following:

- Initial T/A logging indicated the entry of natural gas into the annular space behind the production casing.

- Shut-in annular pressure behind the production casing of the subject gas well built-up to more than 600 pounds per square inch gauge (psig).

- Vent-rate flow tests completed on the annular space outside the production casing indicated flows on the order of 0.166 to 0.335 thousand cubic feet per day (Mcf/day).

- Eighty gas vapor and dissolved gas samples were analyzed for molecular and geochemical (including isotopic) composition. Water samples were also collected from the drinking water wells for geochemical analysis. Fifty of the gas and isotopic samples were collected from three private water supplies, and 30 of the gas and isotopic samples were collected from gas wells. Analysis included cation-anion balance (CAB), water type (trilinear analysis) and reduction-oxidation potential (redox), in order to estimate the effect of microbial populations on the groundwater as well as the dissolved methane. This geochemical analysis provides an indicator whether the gas is being recharged in the aquifer from its source.

Based on the results of mechanical integrity tests, the subject gas well was selected for remedial action to reduce the flow of natural gas in the wellbore outside of the production casing. Remedial efforts included the perforation of the 5½-inch production casing and remedial cementing behind the production casing.

Post-remediation T/A logging of the subject gas well indicated that the remedial actions reduced natural gas migration in the annular space behind the production casing. Post-remediation shut-in pressure build-up testing indicated a 60% reduction in shut-in pressures as well as a declining trend in pressures. This decline indicates that the source is reduced, and the gas is depleting. Further, the shut-in pressure build-up curves indicated that with successive periods of controlled venting, shut-in build-up pressures will continue to decrease. Over successive months, shut-in build-up pressures were further reduced by 75%. These results suggest that natural gas that remained in proximity to the subject natural gas well was above the Marcellus and may have been artifact pressures on a depleting trend (**Figure 8**).

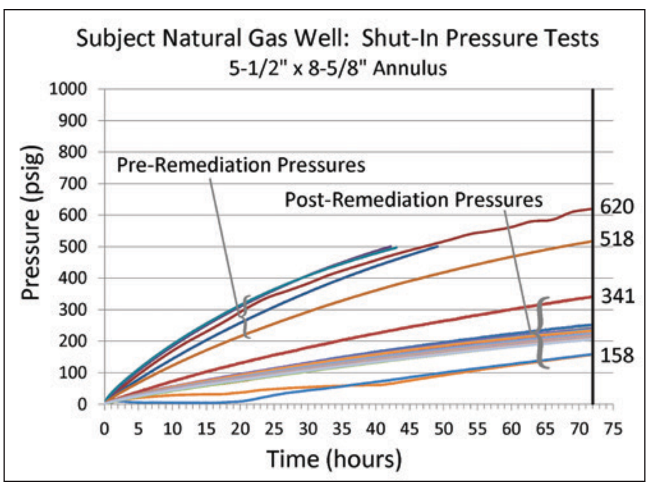

Figure 8
Graph of decreasing shut-in pressures after remediation.

Changes in the isotopic composition of dissolved methane in the water supply wells indicated increasing oxidation, suggesting the source of methane in the residential water well had been eliminated. The results of the well integrity analysis of the subject gas well indicate the following:

- Natural gas found in the subject water supply wells was similar in composition to the natural gas found at the subject natural gas well.
- Three neighboring gas wells did not appear to contribute natural gas to the subject water supply wells.
- The concentrations of dissolved methane gas at the subject water supply wells appeared to be depleting.
- Changes in isotopic composition of methane at the water supply wells indicated that the dissolved methane in the groundwater was not being replenished.
- Natural gas in the wellbore of the subject gas well, above the production zone, appears to be depleting.

Remedial actions performed at the subject gas well appeared to have reduced gas migration. The results of numerous well integrity tests indicated that natural gas in the wellbore of the subject gas well, above the production zone, was depleting — and the occurrence of natural gas in the subject water wells was decreasing. No further remedial action was recommended for this well.

Conclusion

With the rapid development of the Marcellus Shale, an increase in alleged natural gas migration incidents has been observed in several areas of the region. Although studies of groundwater contamination relating to the alleged incidents have been well documented, studies of the oil and natural gas wells themselves have not. As presented herein, the assessment of well integrity for natural gas migration investigations requires a holistic approach and a detailed evaluation process. The presented well evaluation process has been developed and refined through the completion of more than a thousand wellbore integrity studies. A multitude of well integrity tests and evaluation methods are available, each with unique challenges. While any one test may indicate a potential concern, no single finding alone is sufficient; rather, when evaluation methods are used in concert, a proper assessment of well integrity can be made. Additionally, when completed properly, an assessment of well integrity will help identify potential concerns relating to the natural gas migration investigation that may require remedial measures.

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