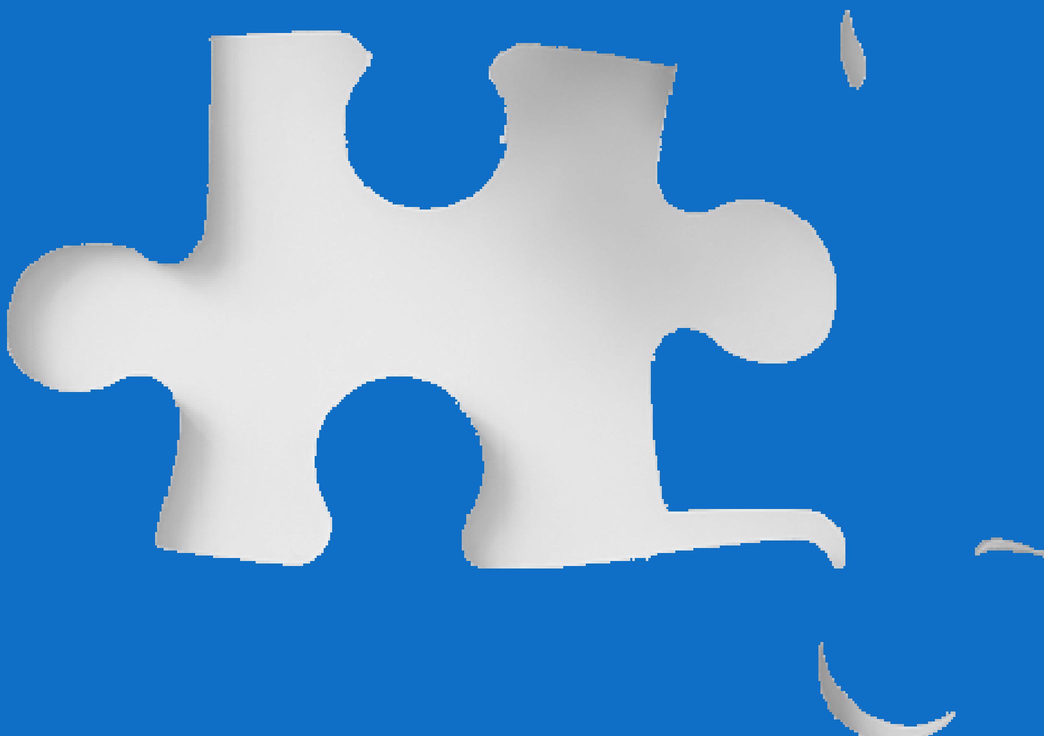
Application of Well Integrity Methods for Gas Storage Wells



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ALL Consulting

Presented at:

23rd IPEC Conference

November 8-10, 2016

New Orleans, Louisiana

Outline

- Introduction
- Assessment of Well Integrity
- Temperature Logging
- Noise Logging
- Cement Evaluation Logging
- Corrosion Logging
- Surface Well Integrity
- Recent Lessons Learned
- Summary

Pneumatic Controller

Source: ALL Consulting

Introduction

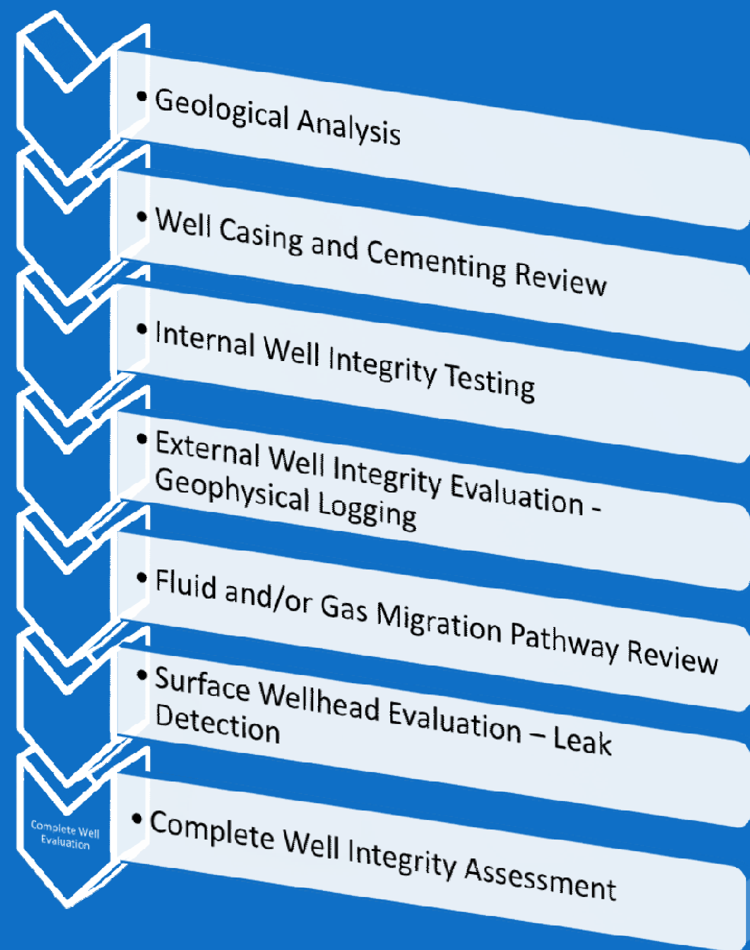
- Various well integrity test methods have been used for decades.
- Effective testing requires defining objectives and procedures, necessary well configuration, testing objectives, and methods for analyzing results with other relevant information.
- Well preparation and stabilization is critical.
- An effective quality assurance plan and quality control measures are critical for well integrity testing to avoid ineffective data collection.

Well Integrity

- Evaluation/assessment of gas storage well integrity is critical to operations
- What is Well Integrity?
  - Lack of significant leakage within well and/or wellbore
  - Both internal and external integrity must be considered and evaluated
    - Internal Integrity: Well casings, tubing, packers, etc.
    - External Integrity: fluid movement external to the production casing or other casing strings.

Holistic Well Evaluation

- Process to determine well integrity
- Holistic approach to overall well integrity using many tests
- No single testing method is sufficient to fully assess well integrity.



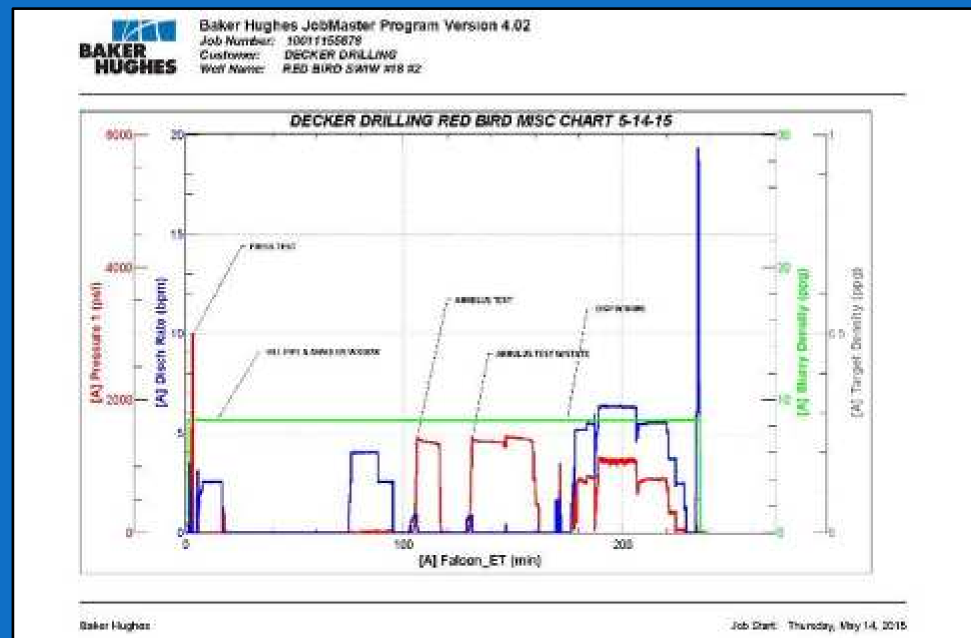
Internal Mechanical Integrity

Source: ALL Consulting, 2015

- Typically demonstrated by pressure testing production casing-tubing annular space
- Regulatory agencies normally set testing guidelines and pass/failure criteria

Internal Mechanical Integrity Testing

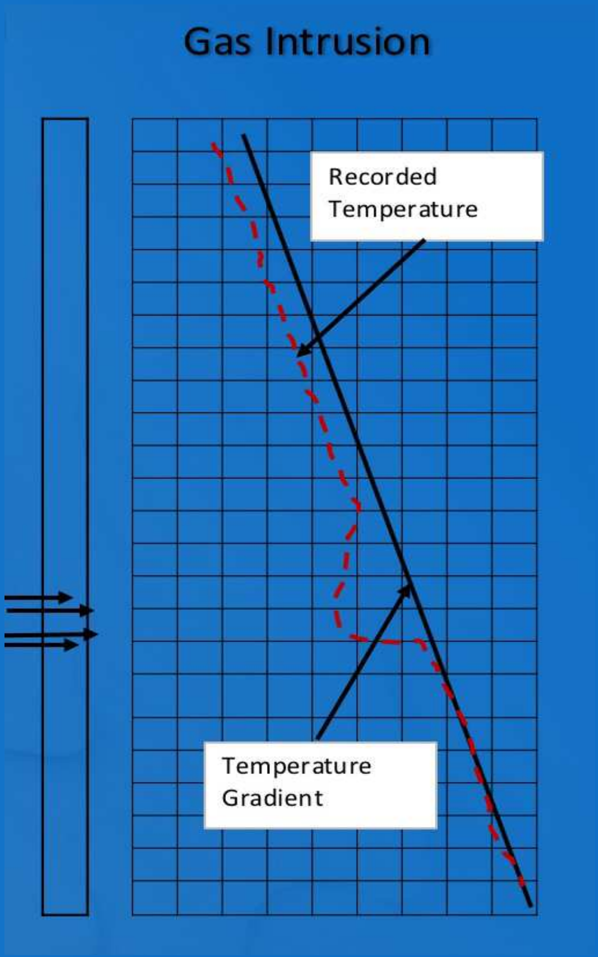
- Production casing-tubing annulus must be isolated
- Test at least to maximum operating/injection pressures
- Must maintain acceptable pressure over required time



Source: ALL Consulting, 2015

Temperature Logging

- Temperature logging - one of the oldest forms of production logging.
- Normal gradient - temperature typically increases uniformly with depth in natural setting
- Deviations from normal gradient may be from fluid entering, exiting, or migrating within the wellbore



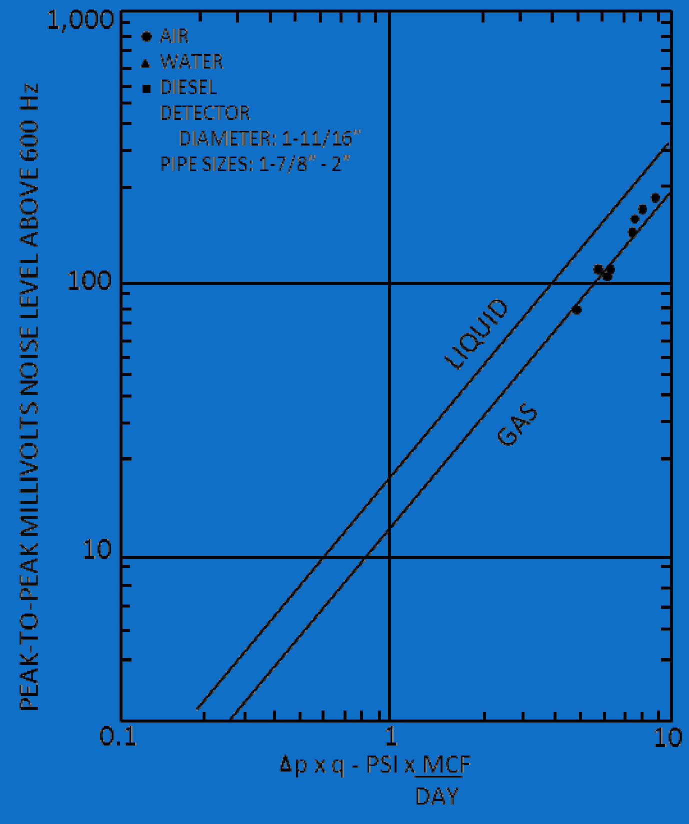
Noise (Audio) Logging

- A Noise Log is essentially a series of audible sound measurements recorded at intervals throughout a wellbore and filtered into frequency ranges
- Turbulence from fluid flowing through a constriction generates noise recorded on the log
- Noise Logs used in the external well evaluation process can indicate:
  - When and where flow is occurring
  - What type of flow:
    - Single-phase flow (gas or fluid flow)
    - Two-phase flow (gas through fluid flow)

Gas Migration and Noise Logging

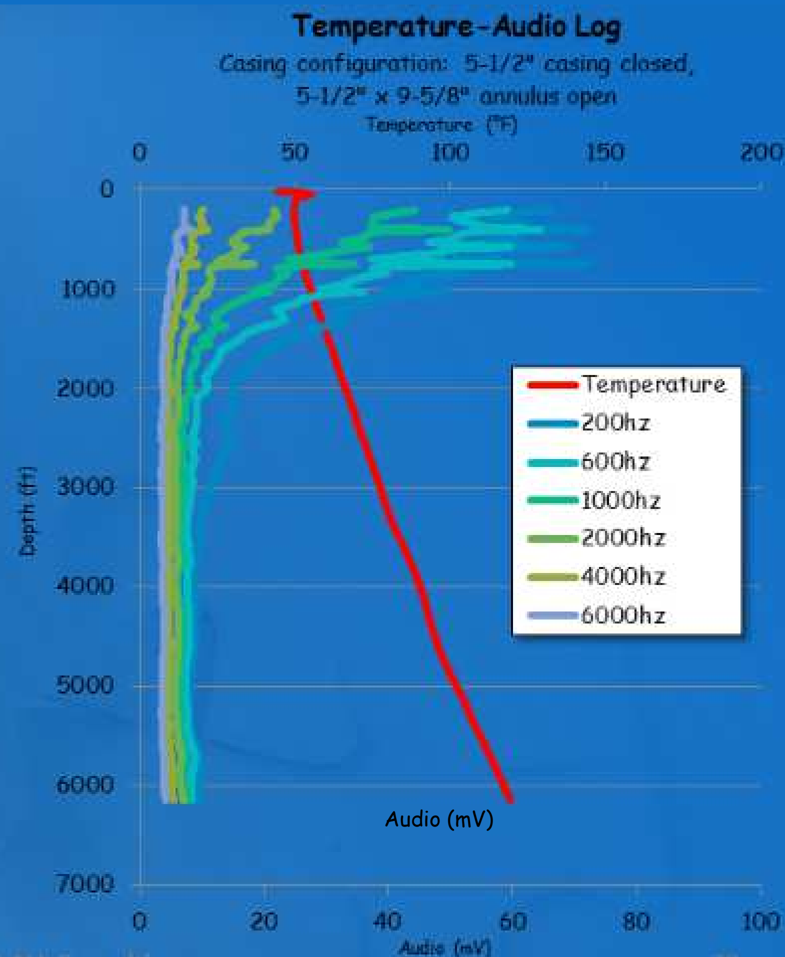
- When evaluating gas movement behind pipe opposed to liquid, audio analysis is a fundamental tool.
- As McKinley documented in 1979, gas movement makes more noise than liquid movement past a detector.
- Although noise logging can be used to assess liquid movement behind pipe, it is ideal for assessing gas movement!

Fig. 2 – Noise level generated by flow past a detector.

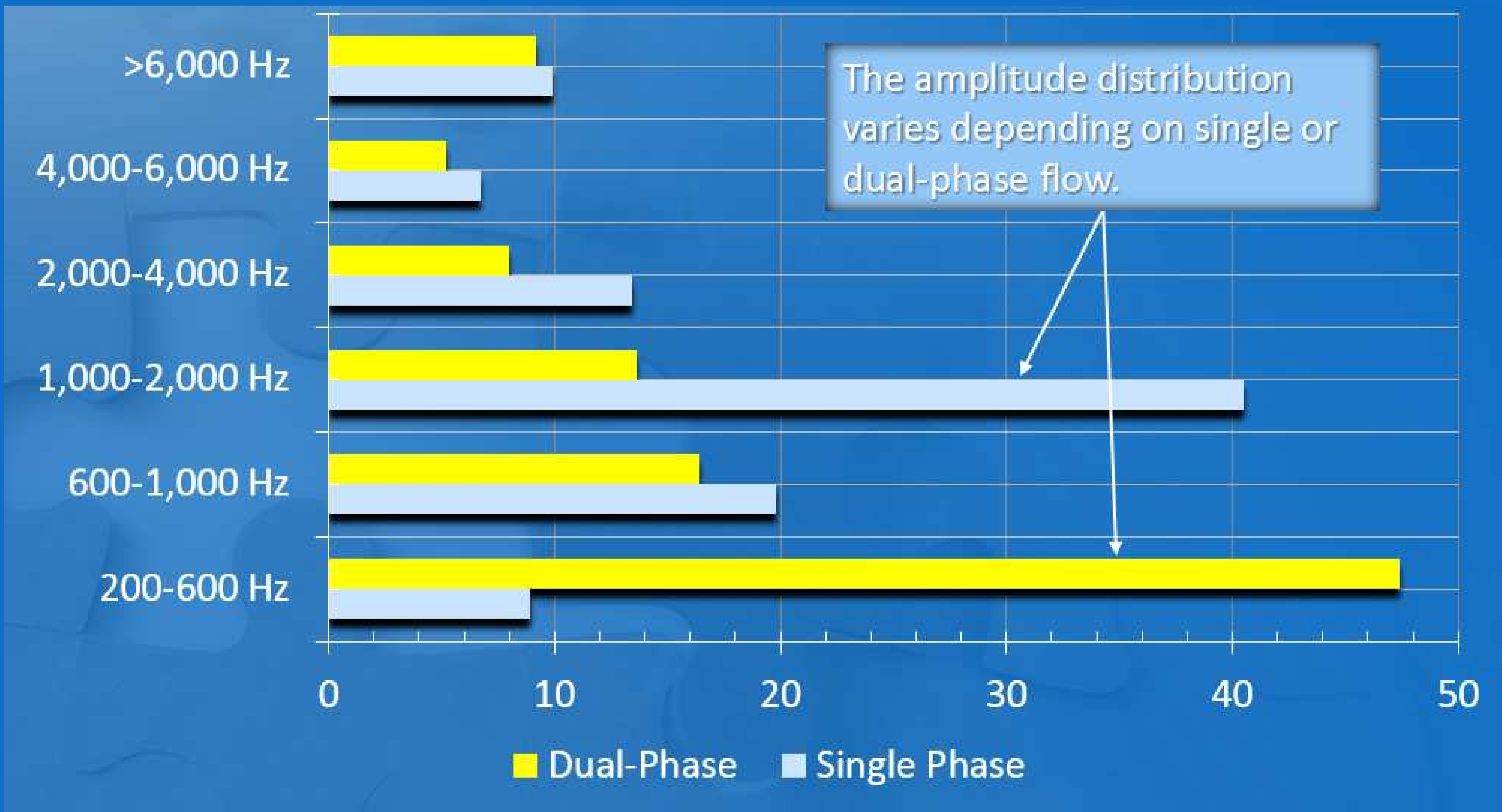


Noise Logs

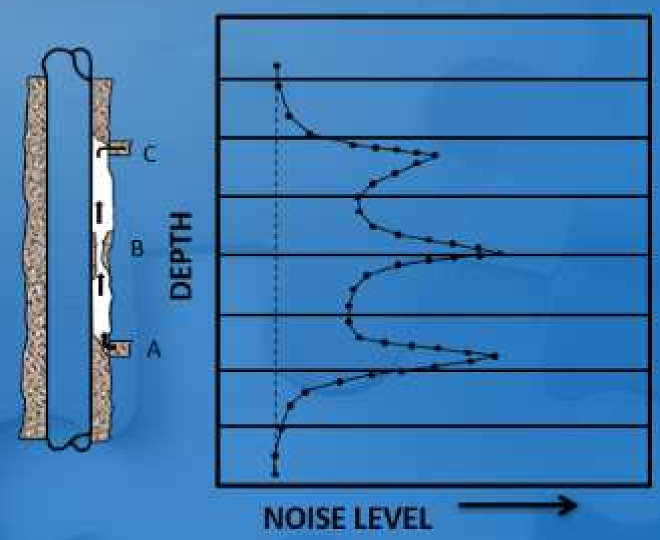
Frequency Cuts	Significance
Below 200 Hz	• Noise in the range from 10 Hz to 100 Hz generally accounts for mechanical or surface noise including cable vibrations caused by the motors of logging trucks, by lubricator motion, and other surface disturbances
200 Hz – 600 Hz	• Eliminates most surface noise while still being low enough to detect the action of gas moving upward through liquid (*McKinley, Bowler and Rumble, 1973*). • Discrete bubbling – reflected by a spectrum peak in the 300 to 600 Hz range (*McKinley, Bowler and Rumble, 1973*) • Mild Slugging – spectrum peak above 200 Hz decreases with only a slight indication of bubble peak. (*McKinley, Bowler and Rumble, 1973*) • Severe Slugging - more energy is transferred into a band around 200 Hz. (*McKinley, Bowler and Rumble, 1973*) • Above 200 Hz, channel type leaks exhibit the same frequency structure as does free-stream, grid-generated turbulence (*McKinley, Bowler and Rumble ,1973*).
1,000 Hz – 2,000 Hz	• Noise spectra show presence of free-stream turbulence which is characteristic of single-phase flow (*McKinley, Bowler and Rumble, 1973*). • Above 1,000 Hz two-phase leaks are indiscernible from single-phase leaks (*McKinley, Bowler and Rumble, 1973*).



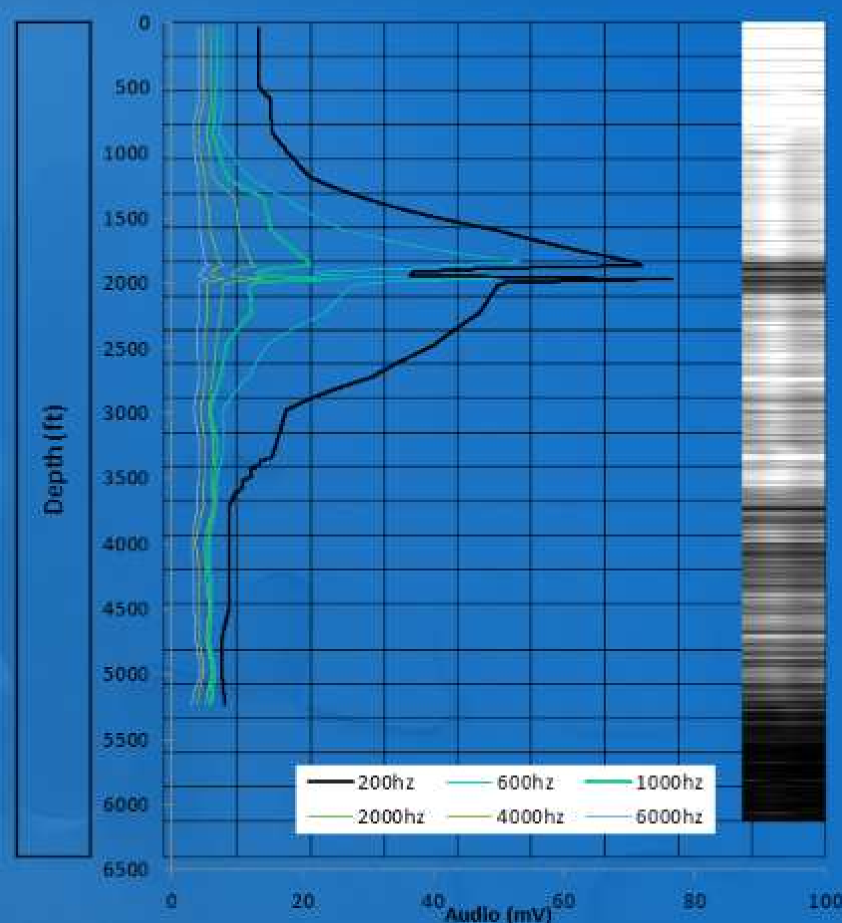
Typical Noise Distribution



Restrictions and Two-Phase Flow

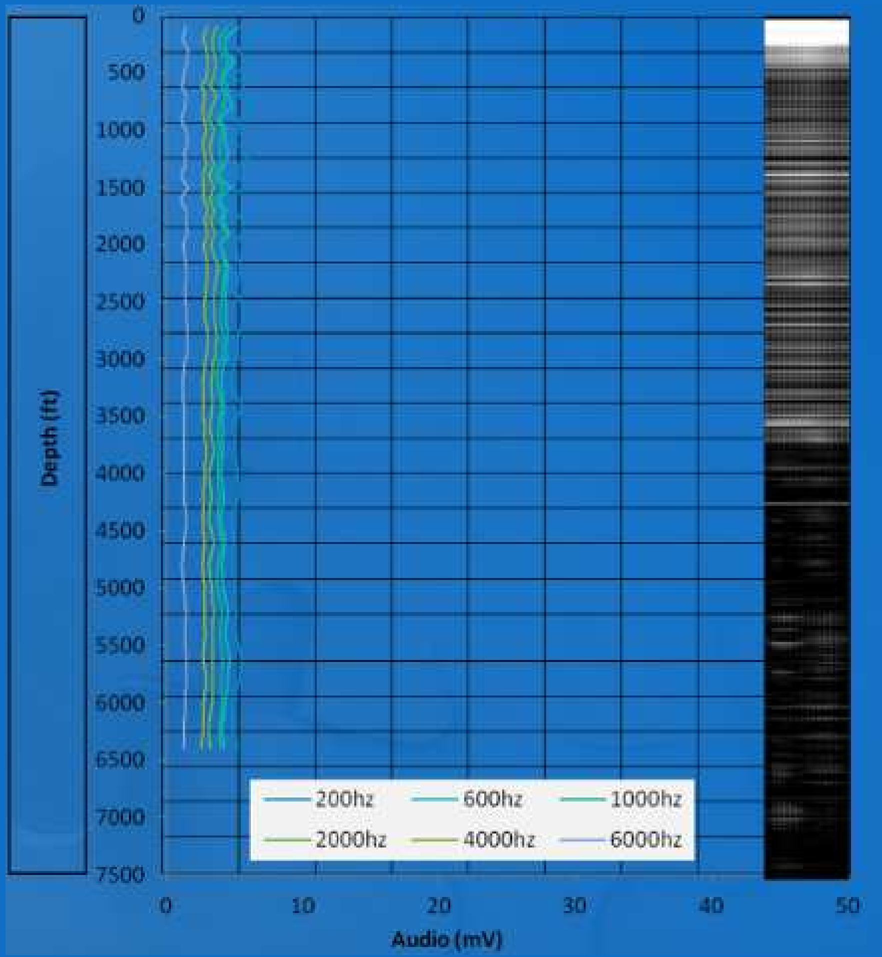


NOTE: the example above is from McKinley (1973) and although a great example, actual conditions can vary. The example to the right shows two-phase flow and a restriction as evident from the RCBL.



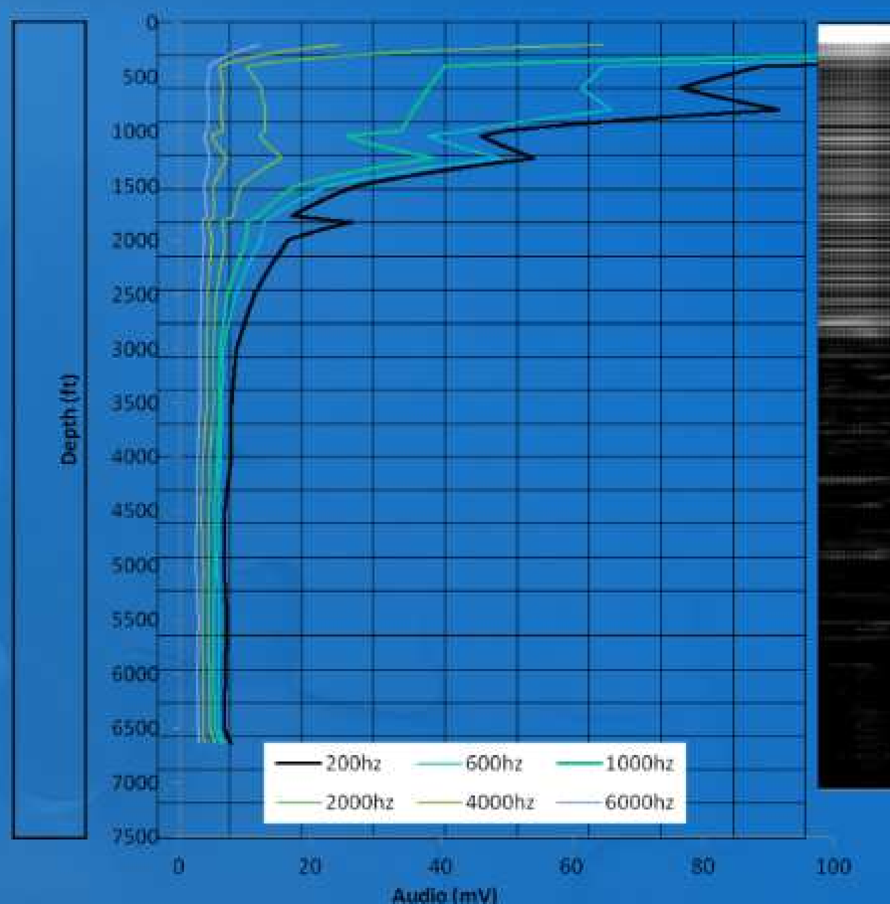
Noise Log with Cement Bond Log

- Noise logging rarely yields ideal results
- Even with good cement, audio amplitudes within the 30 mV range are common
- Sometimes a near perfect log is obtained. The example is void of near surface disturbance, which is uncommon with noise logging (i.e., increased noise activity in the upper 500').
- Note: most noise logs have settings controlled by the logging engineer; logs can vary based on factors other than EWI



Mid-Section Gas Intrusion

- In this example, gas intrusion is observed above 2,000' with apparent flow upward.
- Flow appears to be single phase flow (gas only).
- The noise log confirms the absence of deep gas in the annular space.



Temperature and Noise Logging

- Temperature and noise (T/A) logging, in association with cement evaluation type logging, is likely the most useful when attempting to assess gas movement behind pipe .
- Effective T/A logging requires planning and well preparation.
- T/A logging should be complimented by other information (e.g., vent rate, RCBL, etc.).
- T/A logs can be used to confirm well integrity relative to gas movement behind pipe.
- T/A logging can confirm the general source (e.g., storage zone versus shallower interval)

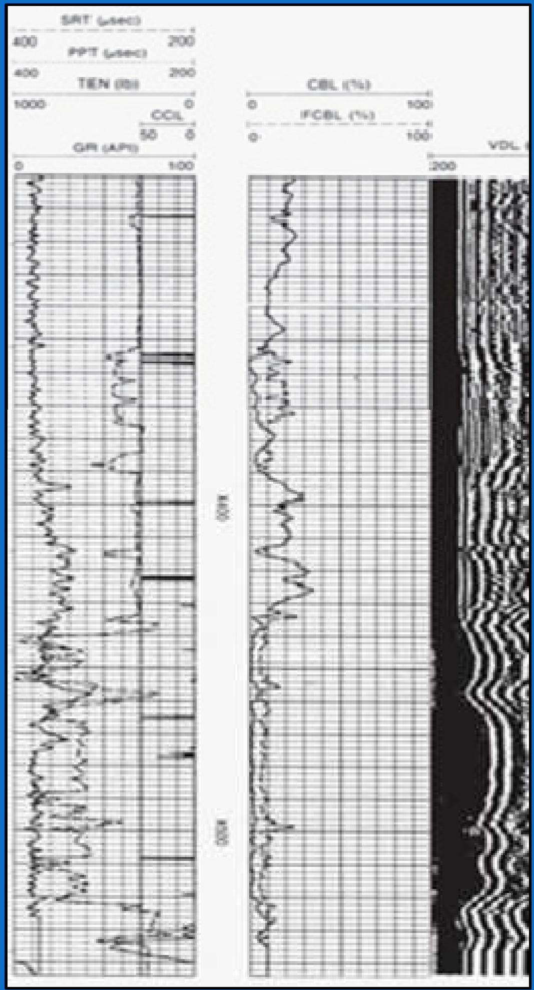
Source: ALL Consulting, 2013

Quality Control for T/A Logging

- Logging practices must be standardized to ensure consistent results.
- The well must be properly prepared prior to logging.
  - Production tubing should be removed.
  - All casing and annuli must be completely liquid filled.
  - Wellbore should be refilled, if needed, after completion of temperature log.
  - The well must be allowed to stabilize for a minimum of 12 to 24 hours.
- Well must be configure properly to ensure intended results are achieved.
- Logs should be completed in sets to evaluate gas flow under varying wellbore conditions.
  - Production casing closed and surface casing open: Intended to induce flow in annular space(s) to identify and characterize flow.
  - Production casing open and surface casing closed: Intended to evaluate whether or not flow, if occurring, is exiting the wellbore.

Cement Evaluation Logging

- Cement evaluation logs are utilized to locate cemented sections in the wellbore and to evaluate the quality of the cement bonding in these zones.
- Cement evaluation logs do not provide a measure of fluid movement (either water or gas) but can identify where potential void spaces exist or areas where cement may be present but is not bonded to the casing.
- Evaluating cement and cement bond quality in the presence of wellbore gas intrusion can be challenging!
- Multiple wellbore conditions must be taken into consideration to accurately evaluate cement evaluation logs.

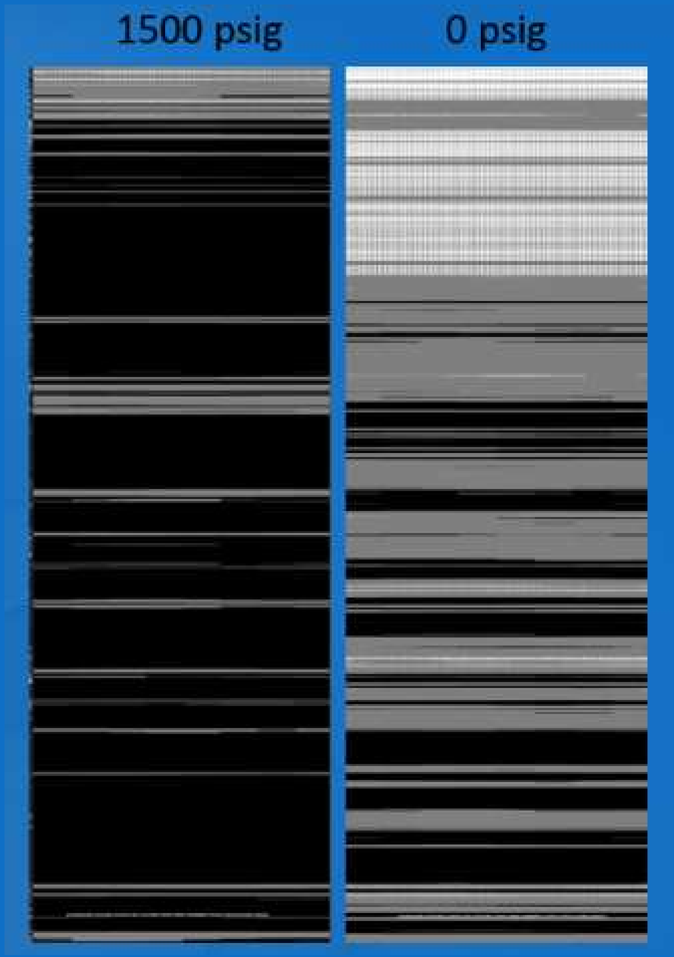


Assessing Casing and Cement

- Prior to considering logging, understanding cementing methods is critical. Insights regarding hole preparation, procedures, cement types, additives, etc. is important.
  - For instance, a lighter weight cement may show differently on a bond log than a heavier cement.
- Cementing Records
- Logging tools used for assessing cement bonding
- Physical testing

Microannulus

- A Microannulus (MA) is typically defined as a small separation between casing and cement where gas can travel, but not liquid
- A misconception is that if a well has a MA, it is continuous over the entire wellbore
- Actual conditions and testing reveal that often times, a MA occurs over discrete intervals (see example)
- Recognizing the presence of the MA is important when assessing EWI related to gas migration in a wellbore annular space



Corrosion

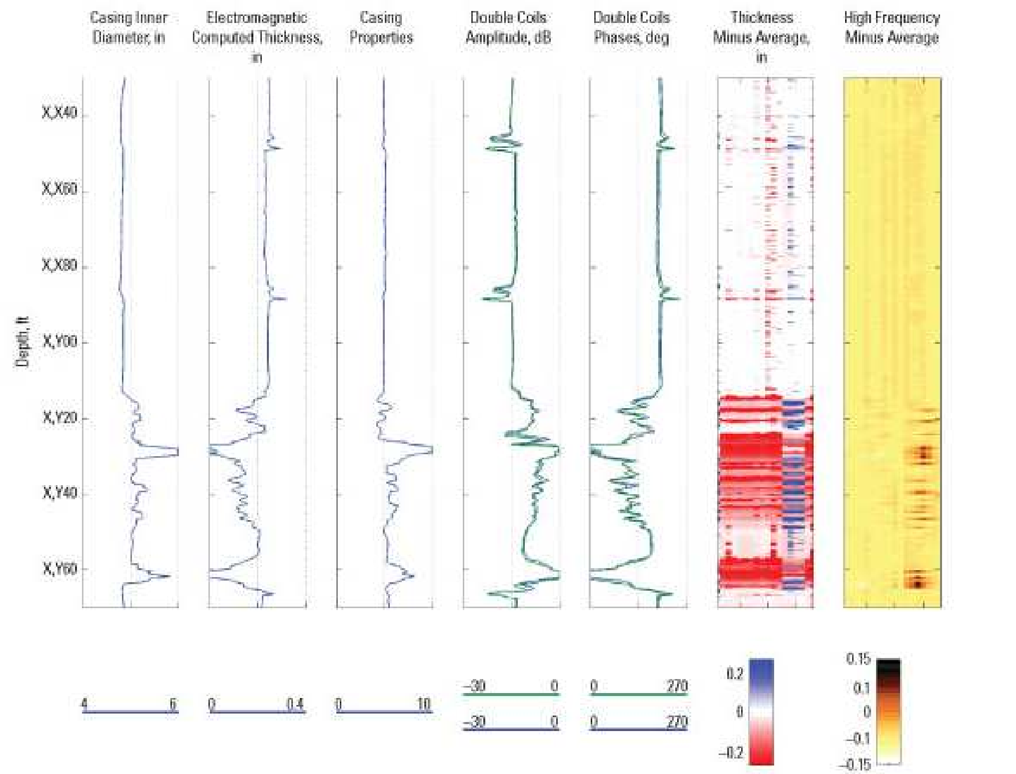
- Because it is almost impossible to prevent corrosion, it is becoming more apparent that controlling and monitoring the corrosion rate may be the most economical solution

Source: DMRM, 2010

Different Corrosion Logging Tools

- Caliper devices
- Corrosion rate devices
- Electromagnetic devices
- Ultrasonic devices
- Composite logs

Electromagnetic Casing Inspection Log



The EM Pipe Scanner electromagnetic casing inspection tool's low-frequency image (second track from right) shows corrosion in the external wall of the 5½-in liner in the perforated interval from X,Y15 to X,Y65 ft. Corrosion is removing metal from the outside to the inside, feeding the invasion of aggressively corrosive fluids and adversely affecting production. Multifinger caliper tools did not detect the corrosion. The high-frequency image in the far-right track also images the perforations.

Source: Schlumberger, 2016

Leak Detection Monitoring

- Surface leak detection monitoring is performed to confirm presence of hydrocarbon leaks at the wellhead.
- Field procedures are developed to ensure that consistent methods are employed and quality data is obtained

Industrial Scientific MXB iBRID Gas Detector

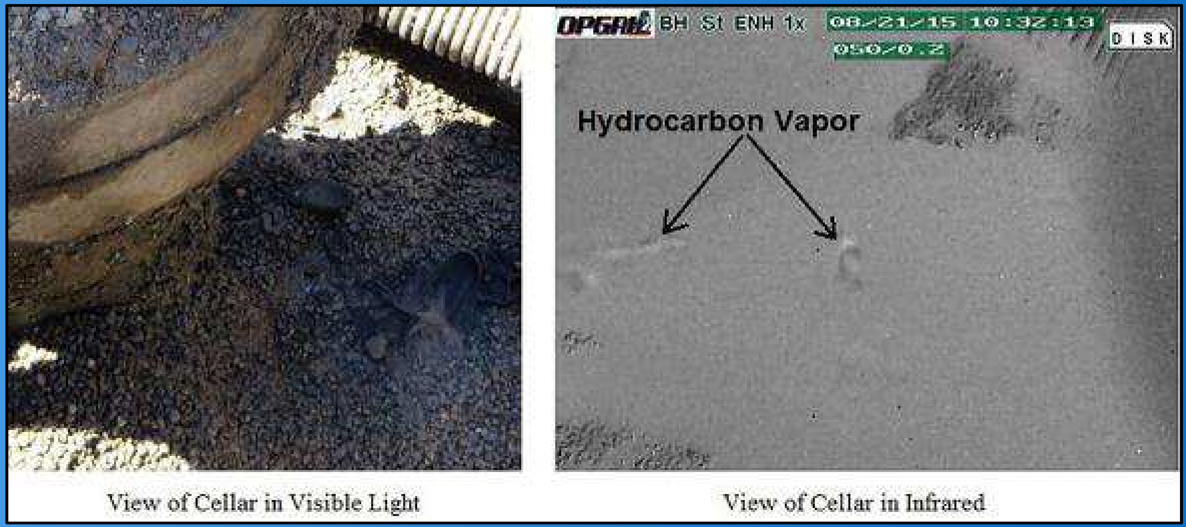
RAE Systems Multi RAE Gas Detector

Infrared (IR) Videography

Source: ALL Consulting, 2015

IR Detection

- Infrared video imaging can be a valuable tool to evaluate well conditions.
- Infrared video can provide a visual representation of gas flow from the wellhead or cellar.



Source: ALL Consulting, 2015

Example of IR Camera Imaging

Wellhead in visible light

Hydrocarbon vapors are visible in infrared

Source: ALL Consulting, 2015

Monitoring Systems

- Active monitoring of injection/withdrawal wells for detecting leaks and pressure changes
- Establishing a monitoring/observation well network to detect potential leaks from the gas storage reservoir
  - Monitoring/observation wells should be installed into the deepest porous and permeable formations directly above the gas storage reservoir
- An umbrella component of a leak detection plan should consist of regional infrared (IR) monitoring using an IR camera
  - Conduct IR monitoring prior to operation of the storage area to establish background conditions
  - Periodic monitoring to demonstrate containment

Storage Well Testing Protocol Considerations

- Consistent cased-hole logging methodologies and well integrity assessment are needed. For example:
  - Wellbores are often not liquid filled for T/A logging
  - T/A logs run at inappropriate speeds (i.e., ~35 fpm is recommended)
  - Multiple logging passes provide better results
  - Logging should not be conducted through tubing
  - Internal mechanical integrity testing should be conducted using defined pressure guidelines with clear pass/fail criteria

Summary

- The assessment of well integrity for gas storage wells requires a holistic approach and a detailed evaluation process.
- A multitude of well integrity tests and evaluation methods are available, each with unique requirements to be effective.
- 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.

CONTACT INFORMATION

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Citation Information:

Arthur, J.D. "Application of Well Integrity Methods for Gas Storage Wells". Presented at the 23rd IPEC Conference, New Orleans, Louisiana, November 8-10, 2016