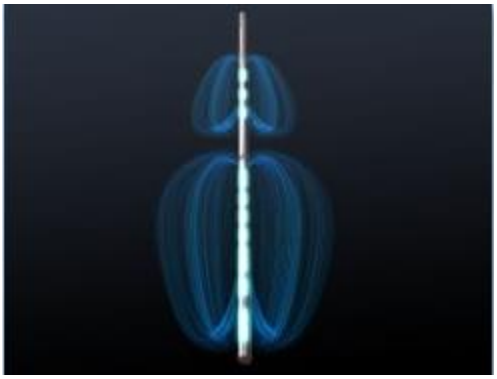
HALLIBURTON

Well Integrity Services

You Can Trust

In Our DNA

We understand the vital role that well integrity plays in maximizing the profitability of oil and gas assets, backed by integrated expertise and a wealth of knowledge from 100+ years of working in every aspect of the oilfield services business. Our Well Integrity Services team is at the heart of all E&P projects, getting the job done efficiently and economically, using some of the leading technology in the industry designed to help mitigate risk and reduce uncertainty. Whether drilling onshore or offshore, conventional or unconventional, single-well platform or multi-well pad, you can trust us to always protect your petroleum system's integrity and containment—it's in our DNA.



Monitoring Well Integrity Conditions

Well integrity cannot be taken for granted. Unexpected well instability, damage, or containment issues, such as corrosion, geomechanical forces, erosion, and geology, can severely jeopardize your asset's infrastructure and reservoir contents. By regularly monitoring wellbore conditions, you can identify potential problems before they incur costs due to repair, replacement, or downtime. Data lead to accurate prediction with the right analysis and the right tools, enabling a planned intervention with a higher probability of success and much lower risk.

Storage, Injection, and CO_2 Sequestration Wells

There are other types of wells besides basic downhole and horizontal, each of which plays a significant role and has its unique challenges that must be monitored.

- Storage wells, for example, service many areas (mid-stream, downstream, utilities, industrial, fuel, base components, and other products), which helps make commerce successful. However, since the wells and reservoir can be cycled between injection and production multiple times a year, considerable stress is placed on the integrity of the containment in place.
- Another case is the emerging CO_2 sequestration wells. Of all the methods currently being tested and evaluated, carbon capture and storage (CCS) is widely considered to be the most practical and effective means to reduce emissions of CO_2 and other greenhouse gases (GHGs) into the atmosphere. CCS involves transporting CO_2 from power plants and other industrial businesses to depleted saline aquifers and oil and gas reservoirs. Once there, the CO_2 is injected into the reservoir via a well, where it is monitored for containment.

Using Technology Tools

Typically, a regular monitoring program is in place for all types of wells—including storage, injection, or otherwise. In some cases, the timing and minimum monitoring requirements are guided by industry regulations. But operating companies often perform more than just these minimum requirements for a better understanding of current conditions.

We employ smart tools, equipped with advanced acoustic, ultrasonic, electromagnetic, and sensor-driven technology to monitor, measure, and evaluate well integrity.

PIPE INTEGRITY

Good pipe integrity helps ensure well stability throughout the life of your well. Tubing and casing are the links to the reservoir, so it is important to understand the condition of the pipe. When there is an issue, speedy determination of the problem saves costly remediation. Our pipe inspection tools help this effort.

Electromagnetic Pipe Xaminer® V (EPX™ V) Corrosion Monitoring Tool

- Quantifies metal loss in up to five concentric strings of pipe in a wellbore
- Uses accurate high-definition frequency (HDF) technology
- No need to pull tubing, so no rig required
- Robust in wellbore environments containing fluids, gases, and nonmagnetic scale
- Examines the whole well in one trip, reducing diagnostic time
- Collects comprehensive information for monitoring programs
- Determining the right solution for a nonconformity in completion projects

Circumferential Acoustic Scanning Tool™ (CAST™) Cement Evaluation

- Highest-resolution scanning technology for cement evaluation on the market
- Provides data on the cement bonding to the pipe
- Runs along with Halliburton's Cement Bond Log (CBL) tool to analyze outer bonding conditions
- Advanced software analysis for additional data on the bonding and cement integrity in the well
- Proprietary log analysis techniques to accurately identify cement conditions—even in challenging situations (e.g. foam or ultra-lightweight cements)

Pipe Integrity Xaminer® (PIX™) Corrosion Monitoring Tool

- Detects flux leakage in and around even the smallest pipe defects
- Provides detailed corrosion diagnostics and monitoring, on the inside/outside of inner pipe
- Uses a series of overlapping sensor pads that run along the inner pipe wall, giving a full-coverage measurement
- Measures flux leakage caused by corrosion via multiple sensors in the pad
- Gives an accurate measurement of interruption in pipe consistency (e.g. from corrosion)

CAST Pipe Inspection

- Provides high-resolution data in cased holes via ultrasonic pipe inspection
- Scans a full 360° – providing a full circumferential profile of pipe and/or cement
- Accurately measures borehole fluid characteristics with a second acoustic transducer mounted in the tool housing
- Collects data to the high side of the hole using a directional subassembly.
- Determines casing thickness for pipe inspection, giving information on the inside/outside of the first pipe
- Delivers real-time measurements for quick decision making

Multi-Finger Caliper (MFC) Tool

- Uses a wide variety of multi-arm calipers to provide high-resolution details about casing or tubing conditions
- Includes accurate measurements of internal radius
- Comes in sizes for most casing and tubing
- Operates up to 24 to 60 arms
- Functions on wireline, slickline, or coiled tubing
- Collects data collected for generating 3D images of casing or tubing

Radial Cement Bond Log (RCBL™) Cement Evaluation Tool

- Captures full 360° data via proven sonic logging technique
- Ensures reliable cement-bond evaluation for a full range of through-tubing logging and casing completions
- Measures small-diameter tubing to large casings
- Determines cement sheath integrity, leaving no room for ambiguity
- Provides the best information available to confirm competency of cement bond
- Delivers comprehensive borehole coverage and clear indication of channels or intervals, equipped with:
    - One omni-directional transmitter
    - Two omni-directional receivers
    - Eight radial receivers

CONTAINMENT – CAP INTEGRITY

Containment is the verification that no product is migrating out of zone into other intervals. Well integrity can be positive, yet reservoir fluids can be moving into another zone. This may be an unforeseen integrity issue or communication out in the formation away from the well. Reservoir monitoring offers insight into changing contacts, saturations, and migration through the reservoir. Regular monitoring helps validate natural barrier integrity. In storage, lost product is a direct cost, and is regarded as lost revenue and a liability. By monitoring the permeable formations above the reservoir cap barrier, you can have further confidence of a proper seal and confinement of the reservoir. The following monitoring tools assist with this preventative measure:

Reservoir Monitoring Tool – 3 Detector (RMT-3D™) Pulsed Neutron Log

- Provides detailed information on the formations around the wellbore
- Gives measurements of saturation for multiple fluids and gases, porosities, elemental analysis, and shale content
- Identifies water flow and other characteristics of the formation
- Provides a time-lapse analysis of the reservoir and zones immediately above (which typically are not expected to change)
    - If there is a change, further inspection is warranted
    - If saturations are changing, the fluid can usually be identified as a known event, or it can be determined that the storage well has a leak
- Characterizes the formation and fluid properties, with a depth of investigation several inches away from the wellbore, providing a different perspective than technologies that only look at the wellbore
- Monitors several factors related to the formation's description, thus, delivering precise data to reduce uncertainty

Temperature Monitoring Tool

- Measures borehole fluid temperatures
- Accurately senses the temperature of the borehole fluid
- Helps find fluid entry, gas leaks, injection zones, flow behind pipe, and even cement tops
- Delivers fast temperature response
- Operates simultaneously with other Halliburton products
- Provides a convenient flow of information to the operator
- Takes measurements from the low-mass probe, resulting in high-resolution data

Fiber-Optic Monitoring Services

A portfolio of fiber-optic distributed and point sensors is used to gather data and evaluate challenging wellbores—from unconventional and mature fields to heavy oil, thermal, and deepwater environments. These technologies generate a profile of your well over a certain time period, as they effectively monitor production, study changes in the near reservoir environment, and provide more information on temperature effects of fluids around the wellbore.

- FiberWatch® distributed temperature and acoustic sensors (DTS/DAS) — provide evidence of fluid movement along the wellbore throughout the well life
- Wireline-conveyed SmartFiber™ sensors — provide accurate pressure and temperature measurements along the entire wellbore simultaneously to improve evaluation of fluid movement over time
- Coiled-tubing-conveyed SPECTRUM® diagnostic services and wireline-conveyed FiberLog™ retrievable services (as well as permanently deployed and pumped fiber applications) — provide unique strengths with respect to fiber conveyance to fit the need for any downhole application

Diagnosing Well Integrity Problems

When a barrier is suspected of failure, many of the same technologies used in monitoring can help identify the location and describe the extent of the problem. Halliburton also employs new technologies to expand the knowledge of such failures and more accurately determine their location. This is important, as it identifies immediate problem areas that need treatment and how they may be repaired.

Shallow Flows

Shallow flows of gas or liquid create hazardous conditions near the surface, caused by a loss in well integrity. This problem can develop quickly or over time, on land or offshore, making it difficult to find and repair. Repairs range from simply pumping a resin-type material from surface, to more complex operations requiring multiple steps.

Halliburton has developed diagnostic packages to help detect and map out these events. We have the technologies, tools, and experience to effectively plan and execute these operations, including:

- Array acoustic noise logging, pulsed neutron logging, and temperature monitoring
- ACX service — to efficiently locate and map shallow flows, identifying both the path of flow and the flow source
- RMT-3D tool — delivers formation data, and identifies water flow and gas influx that may be in a channel

Leaks

Casing, tubing, packers, cement, and other wellbore components can fail in a variety of ways, causing leaks. Pinpointing the source of leaks helps you identify small problems before they manifest into larger issues that can damage your well, or permanently decrease productivity.

Planning Phase

Planning is one of the most critical steps in finding a leak, as it reduces time and cost. Depending on the leak, openhole and cement evaluation data may prove to be very important to overall understanding of the situation. Multiple leaks in a well can be very challenging, and, in some cases, make deciphering well behavior puzzling. Halliburton can help gather and review the pertinent data to assist with the planning phase and ensure proper detection of leaks, along with appropriate repair operations, if needed. We take the following considerations into account:

- If leaks are suspected as a result of corrosion, perhaps rendering the well unfixable, we would run the EPX V tool to determine the extent of the corrosion. This may answer the question of whether to move ahead or not, i.e., proceeding to repair.
- If there are multiple leaks, we would typically identify the largest leak first, and then move to the smallest, manipulating the well through the leak or flow points, if possible. This may include stimulating the leaks through injection operations. Inner leaks with easy access may be corrected first, along with quick repairs, if possible, such as a gas lift mandrel or a slightly opened sliding sleeve.
- The leaks' behavior, trends, and suspected locations will drive the actual planning and direction of the operation, with multiple contingencies to help illuminate downtime.

Inner Well Leaks

Inner well leaks are usually easier to identify, because they are closer and more responsive to changes in the environment. Hardware is carefully examined for leak potential, and then joint connections are examined for smaller leaks. However, many well leaks result from corrosion and are not tied to these obvious locations. In such situations, we would use:

- ACX service — designed to run in continuous mode for just this scenario. If the leak is not at a hardware location, then taking stations alone could miss the leak point or take a long time to find it.
- EPX V tool — runs in combination with ACX service to find the entry point and fully describe the extent of corrosion damage. This information is critical to calculate repair types and costs.

Outer Well Leaks

Outer well leaks can be caused by corrosion or by a loss of integrity in the cement. These leaks are best examined by continuous logging to ensure data is collected over the entire well, including the leak. Having a corrosion log or the cement evaluation that was initially performed on the well, along with openhole information, is also useful for analysis. Other considerations include:

- Such leaks may limit stimulation efforts, reducing the amount of energy that is possible from the leak and sometimes limits the time to produce.
- A shut-in pass and a comparison with the active leak can be helpful in indicating where the leak is located.
- It is best to keep the leak flow in the same direction, as reversing direction may temporarily plug the leak, thus, preventing proper identification and analysis.
- Once areas of interest have been identified from a continuous pass, stations can be run to gather more information or data, as needed. This can be for additional processing or for a more detailed 2D flow map.

Very Small Leaks

The Halliburton Acoustic Conformance Xaminer® (ACX™) service has experience with challenges presented by very small leaks. We have found that:

- In most cases, they require shut-in logging passes and active leak logging passes.
- The size of the leak may reduce the operation to stationary passes only.
- The stations should be analyzed to ensure there is no intermittent flow going by the tool. If so, stations can be extended or repeated.
- Shut-in and active leak passes will be compared, and the small leak over any length of the well will show up as a delta between passes.
- Temperature is always recommended with any diagnostic runs, including the ones that fall into the “very small leak” category.

Resolving Well Integrity Issues

Repair Solutions

Once the problem has been found and explored, an economic solution needs to be provided to resolve the issue and bring back the well's integrity. There are several technologies available for repairing integrity issues – from mechanical solutions to cementing and specialty fluids – and each has its advantages. Consultation is needed to determine how long the repair will take, the objective of the repair, and risks permitted in the operation. Through collaboration, the right solution and options can be decided upon, thereby, minimizing costs for the desired operation.

Conveyance Independence

One way to mitigate costs is through conveyance flexibility, or independence. There are multiple conveyance systems to deliver mechanical- or fluid-related treatments. Each conveyance system is tied to multiple solutions that are available in our Halliburton arsenal.

Solutions for integrity renewal can be conveyed via:

- Wireline
- Slickline
- Relay DSL
- Coiled tubing
- Pump

Mechanical Solutions

Mechanical solutions are usually centered around plugs or expandable sleeves. Numerous safety and economic benefits accompany this capability. These benefits become even more significant as well parameters become more severe. The ever-present goal is to reduce completion CAPEX and to maximize net present value.

- Mechanical Isolation
    - Plugs
    - Through-tubing bridge plugs (where restrictions exist)
    - Tandem plugs
    - Casing patch
    - Expandable screens
    - Expandable packers

Cementing and Specialty Fluids

Cementing and specialty fluids offer additional treatments that are quite effective and economical for certain conditions. These types of repair typically require more steps; therefore, more risks may be present. However, some of the most effective and long-lasting well integrity repairs can be achieved using these technologies. Consider the following:

- Some treatments might be an easy application from surface, while others may need well preparation work before treatment.

- These treatments are usually required for flow behind pipe, reservoir situations, and other scenarios where mechanical solutions are not an effective or possible treatment.
- In some cases, the ultimate solution may be a combination of techniques.

The goal is to have the right application to maximize your return on investment. Our extensive range of Halliburton chemical solutions combine specialty chemical products and services to enable maximum performance and efficiency from your operations. We are committed to providing unparalleled technical expertise and superior local service through cost-effective application of customized specialty chemicals for the life of the well, including the following cement and specialty fluid type treatments:

- Cement
- Polymers
- Specialized cements
- Resin
- Low-viscosity sealants
- Specialty chemicals

Summary

Halliburton has the experience and technologies to monitor, find, and resolve your well integrity issues. Collaboration efforts are necessary to ensure good planning, recommend the appropriate solutions, and achieve successful operations. You can depend on Halliburton to provide well integrity you can trust.