Underground Gas Storage Well Integrity

A Fit-for-Purpose Program of Solutions

LEADERSHIP THROUGH EXPERIENCE

Wild Well leads the industry by responding to 80% of the world's well control emergencies and excelling in engineering and operational support activities throughout the life cycle of a well.

Backed by more than 40 years of experience, our team of experts develop new, innovative technologies and methodologies to assist operators in the ongoing regulatory developments that affect the daily practices of operations worldwide.

RECENT WELL INTEGRITY EVENTS

The Pipeline and Hazardous Materials Safety Administration (PHMSA) Interim Final Rule (IFR), issued in December 2016, places additional requirements on gas storage operators within the United States. The IFR discusses PHMSA's desire for operators to adopt minimum procedures for operations, maintenance, integrity demonstration and verification, monitoring, threat and hazard identification, assessment, and anomalies that affect safety.

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1. VERIFY that the pressure required to inject intended natural gas volumes does not exceed the design pressure limits of the reservoir, wells, wellheads, piping, casing, tubing, or associated facilities;
2. MONITOR all wells for the presence of annular gas or liquids on a periodic basis;
3. INSPECT the wellhead assembly and attached pipelines for each of the wells used;
4. CONDUCT periodic functional tests of all surface and subsurface safety valve systems and wellhead pipeline isolation valve(s) for proper function and ability to shut off or isolate the well and remediate improperly functioning valves;
5. PERFORM risk assessments in a manner that reviews, at a minimum, the API RP 1171 criteria to evaluate the need for subsurface safety valves on new, removed, or replaced tubing strings or production casing;
6. CONDUCT ongoing assessments for the verification and demonstration of the mechanical integrity of each well and related piping and equipment;
7. DEVELOP & IMPLEMENT a corrosion monitoring and integrity evaluation program for piping, wellhead, casing, and tubing, including the usage of appropriate well log evaluations;
8. DEVELOP & IMPLEMENT procedures for the evaluation of well and attendant storage facilities that include analysis of facility flow erosion, hydrate potential, individual facility component capacity and fluid disposal capability at intended gas flow rates and pressures, and analysis of the specific impacts that the intended operating pressure range could have on the corrosive potential of fluids in the system;
9. IDENTIFY potential threats and hazards associated with operation of the underground storage facility;
10. PERFORM ongoing verification and demonstration of the integrity of the underground storage reservoir or cavern using appropriate monitoring techniques for integrity changes, such as the monitoring of pressure and periodic pressure surveys, inventory (injection and withdrawal of all products), product levels, cavern subsidence, and the findings from adjacent production and water wells, and observation wells;
11. ENSURE that emergency procedures are reviewed, conducted, and updated at least annually; and
12. ENSURE that records of the processes, procedures, assessments, reassessments, and mitigation measures are maintained for the life of the storage well.

WELL INTEGRITY SOLUTIONS

To meet the ever-changing needs of underground gas storage operations and avoid the duplication of existing viable activities, we have developed key building blocks to generate a modular, fit-for-purpose well integrity program to satisfy

unique geographic, operational, and regulatory conditions.

Well control and well integrity go hand in hand. Ultimately, all well control incidents link back to a loss of well integrity. The Wild Well solution begins with prevention. Our well integrity services include:

- Well control emergency response plan and drills
- Well integrity program development and assessment/gap assessment
- Wellhead audits
- Wellhead repair using our Special Services team
- Wellbore schematic or barrier schematic development
- Advanced Engineering studies
  - Gas plume dispersion modeling
  - Radiant heat modeling
  - Relief well planning

WELL CONTROL EMERGENCY RESPONSE PLAN

Often overlooked in well control emergency response plans for underground gas storage units, the well component plays a criitical role in the overall security, safety, and emergency preparedness of an operation.

Wild Well's supplemental plan, developed with the operator, addresses the well component using a format praised by regulators for its implementation of an Incident Command System.

Category of Review	Threat or Hazard	Threat/Hazard Description	Potential Consequences
Reservoir	Third-party damage (third-party well operations)	Third-party drilling, completion, and workover activities	— Drilling into, through, or adjacent to the storage reservoir could result in loss of containment — Production well stimulation damages to storage well — Poor cement bond that could result in inability to meet design performance requirements — Loss of stored gas inventory — Damage to third-party/public property and personnel
		Third-party production, injection, or disposal operations	— Decrease in field performance (both working gas cycling and deliverability) — Loss of stored gas inventory — Safety hazard if pressure rating of production facilities are not as high as storage pressure — Inability to meet design performance requirements — Damage to third-party/public property and personnel
	Geologic uncertainty	Uncertainty of extent of reservoir boundary	— Gas migration beyond control of storage wells — Behavior of field under storage operations different than under production that could result in storage gas loss — Inability to meet design performance requirements — Damage to third-party/public property and personnel
		Expansion, contraction, and migration of storage gas	— Expansion, contraction, and migration due to operations that could result in inability to meet design performance requirements and loss of stored gas inventory
		Failure of caprock	— Vertical gas migration, likely during testing phase, initial activation, or when initial pressure is exceeded that could result in gas migration into shallower zones including water sources — Loss of stored gas inventory — For existing field a potential abandonment or requirement of re-cycling facilities
	Reservoir fluid compatibility issues	Contamination of storage reservoir by foreign fluids	— Wellbore damage caused by drilling and completion fluids, water/chemical floods, H_2S generating bacteria, stored gas quality, etc. — Internal corrosion that could result in a degradation to field performance (both working gas cycling and deliverability) and well and/or pipeline repairs/failures

Table 1: Reservoir Related

Category of Review	Threat or Hazard	Threat/Hazard Description	Potential Consequences
Surface	Third-party damage (surface encroachment)	Surface encroachments	— Buildings/roadways/structures construction, cathodic protection current from pipelines, power line current and overhead wires, expansion of park lands, mining, flood control dams, etc. that could result in: — inability to access, operate or maintain facilities — facility abandonment — reduced ability to site additional wells and facilities due to setback restrictions
	Third-party damage (intentional/ unintentional damage)	Intentional/unintentional damage	— Accidental impact by moving objects (e.g. farm equipment, cars, trucks, etc.), vandalism, terrorism that could result in damage to facilities: — loss of ancillary facilities — well on/off status change — impact to service reliability — impact to neighboring public, storage gas loss
	Outside force—natural causes	Weather related and ground movement	— Heavy rains, floods, lightning, earth movements, groundwater table changes, subsidence, etc. that could result in: — damage to facilities/impact to service reliability

Table 2: Surface Related

Category of Review	Threat or Hazard	Threat/Hazard Description	Potential Consequences
Wells	Well integrity (corrosion, material defects, erosion, equipment failure, annular flow)	Gas containment failure due to inadequately sealed storage well(s), e.g. casing corrosion, cement bond failure, material defect, valve failure, gasket failure, thread leaks, etc.	— Loss of stored gas inventory — Damage to well site facilities and equipment — Safety hazard to company personnel and the public — Loss of use of water sources and/or wells — Decrease or loss of field performance
	Design	Gas containment failure due to inadequately completed wells, sealed plugged well(s), failure of cement squeeze job perforations or stage tool, pressure rating of components, etc.	— Release of gas to the atmosphere — Damage to well site facilities and equipment — Safety hazard to company personnel and the public — Loss of use of water sources and/or wells — Loss of stored gas inventory — Decrease or loss of field performance
	Operation and maintenance activities	— Inadequate procedures — Failure to follow procedures — Inadequate training — Inexperienced personnel and/ or supervision	— Loss of stored gas inventory — Damage to well site facilities and equipment — Safety hazard to company personnel and the public — Loss of use of water sources and/or wells — Decrease or loss of field performance
	Well intervention	Gas containment failure due to loss of control of a storage well while drilling, reconditioning, stimulation, logging, working on downhole safety valves, etc.	— Damage to drilling rig or service rig — Loss of tools in wellbore — Hazard to operator and service company personnel on well site — Safety hazard to public — Decrease or loss of field performance — Loss of well
	Third-party damage (intentional/ unintentional damage)	Intentional/unintentional damage	— Accidental impact by moving objects (e.g. farm equipment, cars, trucks, etc.), vandalism, terrorism that could result in damage to facilities: — loss of ancillary facilities — well on/off status change — impact to service reliability — impact to neighboring public, storage gas loss
	Outside force—natural causes	Weather related and ground movement	— Heavy rains, floods, lightning, earth movements, groundwater table changes, subsidence, etc. that could result in: — damage to facilities/impact to service reliability

Table 3: Well Related

SYSTEM GAP ASSESSMENT

Wild Well provides a desktop review of existing policies, procedures, and practices to conduct a well integrity gap assessment. Our proprietary manual provides the guidelines for an exhaustive investigation, but more often it is better to take a broader approach and identify the high-level gaps in a shorter time span.

By clearly identifying the objectives and scope limitations during the exercises (corporate, regional, facility, etc.), the team can provide specific feedback for gap closure or the development of a well integrity manual.

WELLHEAD AUDITS

Wild Well's extensive field wellhead audits provide operators with the latest information for asset protection. By identifying problem wells that require immediate or near-future action, the wellhead audit team can carry out repairs in a timely, cost-efficient manner, providing hot taps, valve drilling, freeze jobs, and resin applications to address sustained casing pressure issues.

Once the equipment has been inspected, the operator should perform an evaluation of the risk of each asset based on the company's internal risk-ranking profile. The following three tables from API RP 1171 provide a list of threats/hazards.

ADDITIONAL FIELD ACTIVIITES

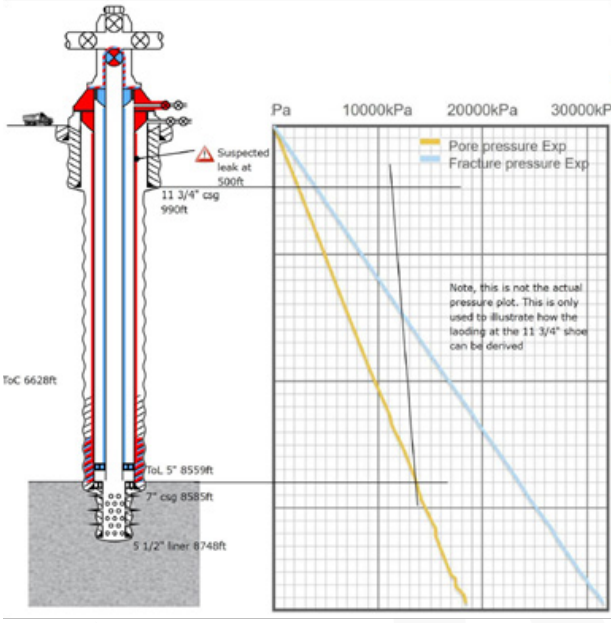
In many older fields, the wellhead equipment could be in a state of disrepair. To continue operating a well that possesses sufficient downhole integrity, Wild Well can re-head the well by removing the existing equipment and installing a replacement wellhead.

As situations arise, the team will develop viable solutions to ensure the integrity of the operations.

DESKTOP STUDIES

The following studies can be provided for specific wells/ locations or as deemed necessary to develop a robust system:

- Updated wellbore schematics
- Updated well barrier schematics
- Well monitoring programs
- Gas plume dispersion modeling
- Radiant heat modeling



- Relief well contingency plans
- Well intervention plans
- Abandonment criteria for aging well stock
- Well abandonment plans
- Generic basis of design (BoD) for new well construction
- Risk assessments

If required, operational support can be provided to the team to ensure that risks are mitigated.

Note: For wells that require a workover or new projects, the implementation of a dual-barrier approach will eliminate most of the event escalations that take a relatively minor event and make it front page news. This methodology is based on an idea that is commonly used in drilling operations. When adapted to production operations, this is also commonly known as nested barriers or a double envelope. This approach calls for a production tubing with packer well design along with a production casing that is capable of sustaining a complete shut-in with reservoir pressure and a gas gradient to surface.

Wild Well has the ability to provide operators with a turnkey solution that will display the well's current operational condition using data collected remotely by the client and updated on a monthly basis along with a breakdown of the variance from the operator's existing plan. If the operator does not currently have a well integrity plan or program in place, Wild Well has the ability to facilitate the creation of an operationalized well

integrity program created by industry experts with diverse backgrounds ranging from wellhead design to production operations, drilling, and well control. The following image depicts a diagram of the current integrity envelopes presented along with relevant geophysical properties (pore pressure and fracture gradient).

APPENDIX

REPORTS REQUIRED BY 49 CFR PART 191

Having a robust system will enable the operator to ensure that well integrity is being addressed. It will also ensure that the four (4) required underground natural gas storage facilities reports can be completed:

1. ANNUAL REPORT: needed to collect operator name, address and contact information; location of the facility; number of wells including injection, withdrawal and observation wells; and facility operational information such as gas storage volumes, gas storage pressures, well depths, gas injection and withdrawal rates, and maintenance information that is conducted to ensure the safety of the facility

2. INCIDENT REPORT: needed for operator reporting of an event that involves a release of gas, death, or personal injury, necessitating in-patient hospitalization, estimated property damage of $50,000 or more, or unintentional estimated gas loss of 3 million cubic feet or more

3. SAFETY RELATED CONDITION REPORT: used to report findings that compromise the safety of the well or reservoir such as casing or tubing corrosion, cracks or other material defects, earthquakes, leaks, or anything that compromises the structural integrity or reliability of an underground natural gas storage facility

4. NATIONAL REGISTRY INFORMATION: needed by PHMSA to identify the facility operator that has primary responsibility for operations through an assigned Operator Identification Number (OPID)

PHMSA is requiring this information because currently there are no annual submittal requirements for underground natural gas storage facilities in PHMSA's regulations that include information about the wells and reservoirs.