2021-IP26: NETL Well Integrity Workshop: Identifying Well Integrity Research Needs for Subsurface Energy Infrastructure

Wellbore integrity, and the potential impact of legacy wells, are key issues for a number of activities including natural gas and hydrogen storage, hydrocarbon and geothermal energy and CO_2 geological storage. In view of the importance of the subject, and with a broader aim to identify new areas of research, the U.S. DOE's National Energy Technology Laboratory (NETL) organised a virtual workshop to identify well integrity research requirements. IEAGHG's James Craig contributed to, and participated in, this virtual event. This IP is a brief summary of some of the issues raised and those areas where further investigation has been recommended. The full report was published on 3rd November 2021 and can be found at:

https://www.netl.doe.gov/energy-analysis/details?id=1f738b0b-9b5f-4cbd-b88f-edd241532b86

This three-day event (May 18, May 25, and June 1, 2021) consisted of six technical sessions and 18 presentations from international well integrity experts on topics of CO_2 geological storage, natural gas, and hydrogen, as well as hydrocarbon and geothermal energy production. There were workshop registrants from more than 10 countries, 4 major oil and gas companies, 14 U.S. states, 8 U.S. DOE National Laboratories, the U.S. Departments of Interior, Transportation, and Energy and regulators from eight of the ten U.S. Environmental Protection Agency regions plus representation from the U.S. EPA headquarters. It should be noted that this was a US orientated meeting so largely focussed on onshore wells. Nevertheless the topics raised and discussed have direct relevance elsewhere.

Technical sessions covered: legacy well characterisation; non-invasive monitoring; modelling and experimental methods; challenging environmental; data-driven approaches; and management for long-term integrity. Participants were canvassed on their priorities for new research and areas of interest. Poll results enabled the organisers to rank these topics and therefore guide the direction of future research. Of the 34 topics identified through the course of the workshop the top 10 topics were:

- Characterising the environmental impacts of well integrity loss
- Evaluating integrity without access (i.e., without re-entry)
- Data-driven, risk-based approaches to prioritise remediation/plugging
- Understanding the prevalence/frequency of well integrity issues
- Developing a well integrity field laboratory to test monitoring, remediation, and plugging techniques
- Origin of leaked fluids
- Leak detection (groundwater, soil)
- Locating legacy wells
- Long-term integrity
- Bond log leak identification

This workshop provided an opportunity to revisit and test current views from a wide range of stakeholders with a direct engagement in wellbore technology, often covered in IEAGHG technical networks. One of the biggest challenges for the development of CO_2 storage sites are older legacy wells. They create a series of unique challenges not least because pre 1960s wells often have poor records that are either missing, erroneous or lack detail. Although onshore wellbores with steel casing can be detected with techniques like aerial magnetometry other techniques, such as gravity gradiometry and high-resolution light detection and ranging (LiDAR), have been proposed where casing has been removed. Operators are reluctant to enter legacy wells because of concerns that doing so may compromise the integrity of the well. Some older wells have also been abandoned with miscellaneous junk, which complicates re-entry.

In many US jurisdictions permits for new wells require operators to define an area of review over which they are required to search for legacy wells before site development. Consequently, operators will need to review available records and conduct site surveys to identify potentially unrecorded wells. The status of the site will have to be documented and any remedial action proposed. An indication of the type of challenge that could be encountered is evident from a natural gas storage survey of old wells from the 1970s and 1980s in California. This exercise has revealed that well records are not necessarily accurate. Wells have often been plugged but at different depths that were inaccurately recorded or they were completely missing. There was a general view that well integrity data has improved over time

Pennsylvania is an example of how one US state has attempted to tackle the issue of dealing with legacy wells. There is a regulatory requirement for well integrity testing of all operating oil and gas wells. This has led to a compilation of a robust primary well integrity dataset. The state also collects hard-to-gather diagnostic data in the context of regulatory compliance, including cement bond logs (CBLs) and other acoustic log data. Difficulties remain in ensuring that some of these data are in machine-readable formats. The state protects oil and gas well compliance data from investigative work, so there are significant limitations on who can use these data, and how. One consequence of having such a dataset is that it can be used to build statistical/machine learning models that can predict or identify when risks for compromised well integrity may be heightened. Clearly, interrogation of datasets needs to factor in missing or comprised entries but the approach could direct analysts towards a more refined investigation.

One of the main risk factors, leakage associated with legacy wells and well integrity, was featured in the workshop. One view expressed is that some well integrity issues, for example sustained casing pressure (SCP) and casing-vent flow (CVF) and associated environmental damage, are still not well understood. Emissions from leaky legacy wells can be poorly constrained and the frequency with which leaky wells impact groundwater is not known in many regions. Temporal variations in leakage, for example episodic leaks that increase or decline in magnitude, can complicate measurements of leakage rates and estimates of cumulative leakage at the wellhead. Moreover, the origin of hydrocarbons and CO_2 in groundwater is complicated. It can be difficult to delineate between naturally occurring and leaked CH_4 and CO_2 in groundwater aquifers. These complications stress the need for sound baseline groundwater quality data acquisition before and after development to confidently detect leakage into groundwater.

There are, however, more promising prospects for dealing with the dilemma that potential leakage might cause. New statistical techniques applied to monitoring from point sources, and over broader areas, could help to identify interactions and potential impacts. Some integrity testing methods were also discussed during the breakout sessions. Geophysical techniques including ultrasonic guided wave technology and light detection and ranging (LiDAR) were mentioned. There was a general consensus that long-term low-cost monitoring methods that are user-specific, standardised, and capable of screening out noise are essential.

The approach for planning of monitoring well integrity was an integral theme. The importance of regulatory requirements, the risk of leakage, practical detection limits, the time required for monitoring, access to the well in question, and the possibility that entering a well could negatively impact well integrity were identified as key determinants. In some circumstances drilling a new monitoring well may be a better solution in terms of impact and cost-effectiveness than re-entering a well with potential integrity issues. Operators should also consider monitoring for free phase instead of dissolved CO_2. Options for well leakage monitoring that could be considered are:

- Atmospheric or soil gas monitoring at the surface
- Monitoring for bubbles (offshore)
- Well instrumentation with distributed acoustic sensing for vertical seismic profiling
- Simulated acoustic logging
- Flow behind casing
- 4D surface-based seismic
- Pressure measurement in aquifers deemed at risk from another well(s)

The emergence of new and more sophisticated monitoring technologies was outline during proceedings. Dr Ruishu Wright from NETL explained the objective of the Embedded Sensor Technology Suite for NETL's Wellbore Integrity Monitoring Project. The unit's function is to develop a suite of complementary technologies that can be used for chemical sensing to detect indicators of wellbore integrity risks before they result in failure. Three different types of sensors are under development: distributed optical fibre sensors; passive surface acoustic wave sensors; and silicon integrated circuit chip sensors. One of the aims of developing these technologies is the elimination of electrical wiring and circuitry at the sensory interface. The technologies are designed to detect the presence of constituents of interest such as changes in pH and express them in a signal that can be transmitted by optical fibre. Oxide-functionalised fibre sensors (SiO_2, Au-SiO_2, TiO_2, Au-TiO_2, ZrO_2) have been demonstrated for spatially distributed pH sensing with stability in elevated temperature (up to 80 °C) and high-alkalinity environments (up to about pH 12.5).

Polymer-based chemical sensing layers with pH indicators have also been developed for use in high-temperature and high-alkalinity environments. The intention is to embed these optical fibre sensors within cement, steel or casing cement. Wireless miniature silicon integrated circuit (SiIC) devices now show potential for application in well and other subsurface applications. Miniaturised devices (at millimeter-scale), with active integrated circuit processing and wireless energy harvesting and storage, could be deployed within well cement. Laboratory demonstration of electromagnetic energy harvesting at 10 s of MHz and wirelessly powered radio operating at 10s of MHz with a 4-cm antenna and a demonstrated reception range of 50 m shows progress with telemetry. The next stage is to progress to field validation which remains an important technical challenge for these subsurface applications. The durability of all subsurface technologies have limitations particularly as environmental conditions become more extreme. Machine learning was advocated as a technique to forecast sensor failure. The report includes a helpful summary of a range of well integrity monitoring/testing methods that were discussed in the breakout sessions. Their pros, cons, and associated research needs are summarised in Table 1 of the report.

Several participants mentioned a need to develop improved methods (i.e., machine learning applications) to detect small signals among noise in both geochemical and geophysical monitoring data and apply fully probabilistic methods to better understand and minimise false positives and false negative responses. Improvements in leakage signal detection would be particularly valuable for interpreting pressures in above zone monitoring intervals. These zones experience pressure variations that are not well understood but could be a diagnostic sign of leakage.

The workshop discussions also highlighted the significance of clear communication. For example, the necessity to articulate the difference between monitoring for evidence of leakage as opposed to monitoring for evidence of defective wells. Some contributors also expressed the view that more research is needed to understand the real outcomes of well leakage. Well integrity may cause leakage but result in little or no measurable impact to receptors of concern. There may be scenarios that could lead to potentially invasive and expensive engineering interventions that have greater or unwarranted impacts.

The workshop also explored some of the engineering aspects of wellbore construction and related integrity. Cement quality could be an issue for wells hundreds of years into the future. Cement longevity needs to be a consideration in assessing life cycle performance and risks to wells. One option to test the longevity of well cements would be accelerated life cycle testing. A large body of research on novel well cements exists, but the state of the industry is not currently known. A roadmap for operators that demonstrates how to implement state-of-the-art well materials was suggested. Protocols for proper cementing and casing programmes relative to different subsurface energy applications would also be a valuable addition to current practices.

Pragmatic questions were raised about the effect of residual drilling mud on well cement integrity at the formation boundary. A number of measures could be applied but their impacts remain open to debate:

- Should a displacement fluid be used to “wash” the borehole prior to cementing?
- Do imbibed drilling fluids effect cement/formation isolation?
- How does the length of the wellbore impact the time for conditioning?
- How should the wellbore be flushed (e.g., laminar flow) before cementing casing?
- How well is industry making sure that there is adequate conditioning of cement casing?

Several workshop participants suggested that a field laboratory could provide excellent value and an opportunity to develop well integrity assessment, monitoring, and mitigation. One proposal suggested that a set of approximately 20 to 30 old wells in Colorado, where plugged and abandoned wells become public domain, could be monitored over time as a public resource for research. Analysis of these wells could provide additional insights. The field laboratory would also be useful for studying the relationship between proximal formation and well integrity. Gas storage fields may also provide a good opportunity for field research and model validation, since some fields have relatively good quality records.

Improvements and the development of mechanistic models was also covered during the workshop. Two schools of thought emerged from the general discussion on this topic. One group promoted the view that the need for data outweighs the need for better models. The alternative viewpoint emphasized the value of improved mechanistic models to address difficult and complex behaviour and the need for more data to validate those models. Advocates for greater data acquisition, particularly higher temporal and spatial resolution to gain a better understanding of well integrity, stressed the necessity for monitoring data. This goal far exceeds the need for better models. There is a stronger basis to develop improved models once more data is acquired.

This workshop provided a new insight into some familiar issues related to well integrity. It covered a broad span of relevant topics and highlighted new technology developments that have exciting potential if they can be proven in subsurface conditions. The workshop has also generated some direction for future research. Meeting participants expressed strong interest in joining a working group to pursue these research topics and further develop future research directions. IEAGHG will also continue to monitor activities in this area and include well integrity in future network meetings.

James Craig
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