THE USE OF HIGH RESOLUTION ULTRASONIC WELL LOGGING TOOLS TO ENHANCE WELL INTEGRITY MANAGEMENT

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ABSTRACT

Quest Integrity has been operating its proprietary ultrasonic intelligent pigging technologies for the inspection of pipelines and tubular assets operated in the energy sectors for the past 20 years. Building on this technology platform, Quest Integrity has developed Quest Well Integrity X-Calliper^{TM} (QWIX^{TM}), a unique well logging tool that collects high resolution ultrasonic metal loss and geometry data sets for well casings. Opportunities to apply the technology in geothermal wells will provide a step change in the resolution and coverage of logging data available for the integrity management of geothermal well casings. The QWIX technology collects millions of data points per log to provide 100% high resolution coverage of the production casing for both internal and external surfaces. The coverage and quality of the data collected allows for the immediate evaluation of casing condition, accurate measurement of corrosion growth rates with multiple logs over time and enables the performance of fitness-for-service and remaining life assessment calculations. This paper presents an overview of the well logging technology along with a case study covering its application in the inspection and engineering assessment of Coal Seam Gas wells.

1. INTRODUCTION

Corrosion of well casings in all environments is a concern for operators and government regulators alike. Operators face safety risks, environmental damage, lost revenue, and reputational damage. Previous investigations have shown that over 25% of all casing failures in the oil and gas industry are the result of corrosion (Kermani & Harrop, 1996). Casing corrosion has also been identified as primary cause of casing failures in geothermal wells (Aydin & Merey, 2021). Government regulators are concerned with conformance to applicable legislation, environmental safety and maintaining public confidence in their oversight of the activities. Within the New Zealand Geothermal sector, these activities are governed by several codes and guidelines (Standards New Zealand 2015; Worksafe New Zealand 2018a, 2018b) which set out expectations for the operation, repair and maintenance of geothermal wells, amongst other well related activities.

The influence of corrosion on casing failures on geothermal wells has been investigated and determined that the casings resistance to buckling was directly related to amount of corrosion (Teodoriu, 2015). Corrosion resulted in significant reduction of the casings' resistance to buckling. Cement cracking was also identified as a potential cause for localised corrosion which can lead to buckling.

As with Geothermal wells in New Zealand, ensuring the integrity of coal seam gas wells in Queensland, Australia is an ongoing concern for operators and regulators alike. As per the Queensland Government's Code of Practice for the Construction and Abandonment of Petroleum Wells and Associated Bores in Queensland, operators must ensure they undertake "monitoring and maintenance of the well integrity during the operation phase to ensure integrity" and must have an "integrity assurance process" in place. Through the introduction of the QWIX, a new approach to the efficient and accurate identification of corrosion has been achieved. QWIX provides field based data acquisition and rapid on location data review capabilities, supported by remote analysis for full casing evaluation.

This paper describes the technology, examples and learnings from a recent coal seam gas well logging campaign in Australia.

2. TECHNOLOGY OVERVIEW

The QWIX tool is a new approach to evaluating casing integrity. By utilising industry leading ultrasonic technology, the QWIX logging tool is capable of providing accurate assessment of the internal and external diameters of well casings. Historically, a multi-finger calliper has been the accepted option for internal casing measurements. Ultrasonic tools are also available, but as they have been designed to evaluate fluids, cement and formations outside the casing, their resolution and accuracy for casing properties is not as high as the QWIX tool. The QWIX tool can provide high resolution images of the casing and identify small anomalies and areas of wall loss. The current range of casing sizes that can be logged is anything above 2in in diameter.

The QWIX tool is run into the wells with a standard wireline or slickline unit. It requires a liquid couplant for the ultrasonic transducers in the tool to function. The tool provides bidirectional logging capabilities, allowing for two passes while running into the well and pulling out of hole. Standard running speed for the logs during the referenced campaign has been 15 m/min.

Figure 1 shows a typical coal seam gas well configuration. The 14in casing is run to a depth of 10m, followed by the 9 5/8 in casing. For the wells in this campaign, the average depth of the 9 5/8in casing was 77.9 m, with a range of 70.3 m to 102.1 m. Next, the 7 in casing with pre-perforated joints below is run. The average depth of the External Casing Packer (ECP) on these wells was 278.6 m (range 146.2 m to 445.2 m), with perforated casing to 618.9 m (range 491.8 m to 723.4 m). Also shown is an example of wall thickness measurements across a section of a well. The black line is the wall thickness averaged around the circumference at each depth and the red line is the minimum measured wall thickness at that depth.

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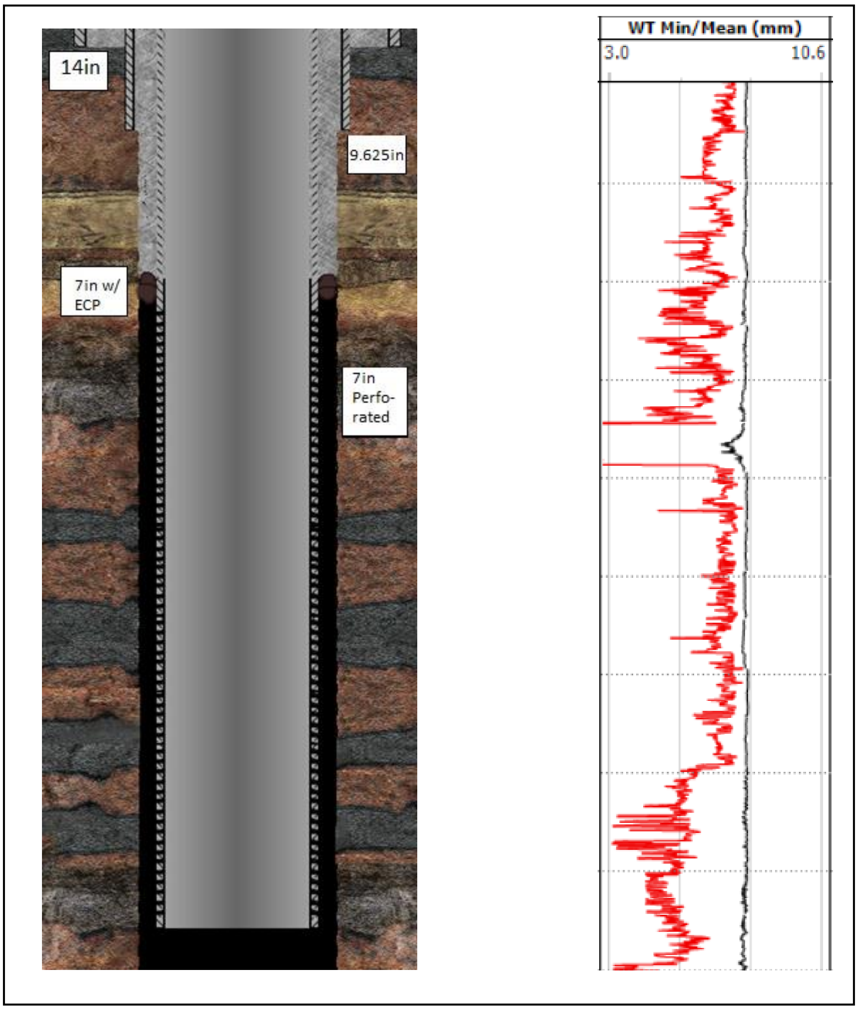

Figure 1: Typical Coal Seam Gas well configuration and example of minimum and mean wall thickness logging data for 8.05mm nominal wall casing (not to scale).

2.1 Validation Work

Due to the importance of accuracy, and the client's reliance on the information to assess their well integrity, extensive work was carried out prior to the field campaign to validate and assess the precision of the QWIX tool for this application. As a proof of capability, a standard 7 in casing sample was modified to create various defects of known size and depth across its length. This casing sample was then logged with a QWIX tool and the results compared to the known defects.

Two assessments of the tool were carried out with this modified casing:

- Identify defects – confirm the presence of a defect and identify how large the defect is
- Quantify defects – determine the amount of metal loss/depth associated with the defect

The performance of the QWIX tool has been assessed at different speeds previously. For this validation work, two different speeds 0.4 m/s and 0.85 m/s were used. In this situation, all anomalies were identified at the log speed of 0.4 m/s and 95% of defects at a higher 0.85 m/s logging rate. The QWIX tool was able to accurately quantify 90% of the defects at both logging speeds. While the specifications of the QWIX tool are that it can identify casing features down to 6.35 mm x 6.35 mm, the validation work proved that irregularities as small as 2.2 mm in diameter were detectable. Wall thickness measurements with 0.025 mm sensitivity down to 0.64 mm accuracy were also confirmed. Sensitivity as used here is the error margin for a wall thickness measurement and accuracy is the minimum wall thickness detectable.

3. CAMPAIGN SUMMARY

During a 45-day period in a recent campaign, 45 wells were logged over 32 days for a Queensland based operator. The 13 days with no logs were either due to rain induced shutdowns or rig operations not having a well available to log. Logging depths ranged from 168 m to 457 m, with an average of 308 m. With the operational efficiency of a QWIX log, multiple wells can be logged each day. During this campaign, 3 wells were logged in a day once and 2 wells on seven occasions. Multiple logs are the result of integrated rig operations allowing for sequential logging at different locations. The operator also had a requirement that if the logging crew was not available within 3 hours due to logging on another rig, the well would not be logged.

Rapid, on site review of logged data was performed to allow the operator to determine if additional casing pressure testing was required to validate log results. The average time between tool coming out of the hole and quick look evaluations being provided to the client onsite was 110 minutes. This rapid response time allowed the rig to conduct any subsequent well testing operations while all crews were still onsite and without having to wait for an extended period. As per the client's defined tolerances, if wall loss features exceeding 50% were identified at a shallow depth (above surface casing shoe) or 70% at a deeper depth, the casing would be pressure tested to validate well integrity and ensure no anomalies below the detectable threshold were present.

The rapid review only reports on anomalies greater than 30% of wall thickness for speed and due to the extra diligence required to evaluate lesser wall loss. Once the crew is finished on location, they will upload the full well data set to allow for a detailed review to be conducted by a log interpretation specialist. This specialist will then create a comprehensive report, detailing all findings and highlighting significant loss areas for the client. The report includes internal and external wall loss, depth, length and width of identified anomalies.

3.1 Summary of Results

The logging campaign has provided great insight into well integrity and casing corrosion for the client. The majority of casing corrosion features were detected on the external surface of the casing, indicating static contact with formation fluids is likely the primary cause of the corrosion.

Well	Shallow		Deep	
	Wall Loss %	Depth (m)	Wall Loss %	Depth (m)
1	60	38.65	63	273.91
2	44	28.53	47	101.49
3	13	7.38	62	136.93
4	43	12.92	70	126.14
5	12	8.11	60	120.02
6	62	10.54	82	381.20

Figure 2: Selection of wall loss data from logged wells

Across the 45 wells that were logged, wall loss ranged from 12% to 82%. Ages of the wells logged were from 2.5 to 11 years, with an average of 7.5 years. Age of the wells did not seem to have a major impact on the levels of corrosion seen. As shown in Figure 3, there is a wide spread of corrosion measurements irrespective of well age. No definitive correlation between well age and wall loss values at shallow or deep locations was identified.

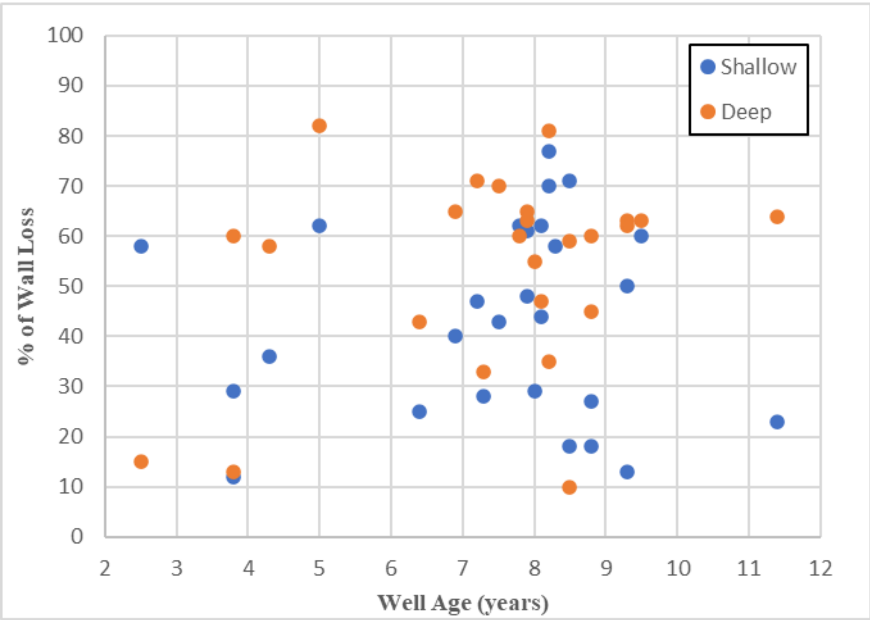

Figure 3: Measured wall loss compared to age of well

Recurrent anomaly types were identified across the wells. Examples of the three most common corrosion types are shown below.

- Band corrosion, where there is uniform corrosion around the circumference of the casing, found mainly near the top of wells (Figure 4a)
- Strip corrosion, where a narrow strip of corrosion runs along the casing, mainly seen near collars (Figure 4b)
- Localised pitting corrosion at a section of casing in mid-well locations (Figure 4c)

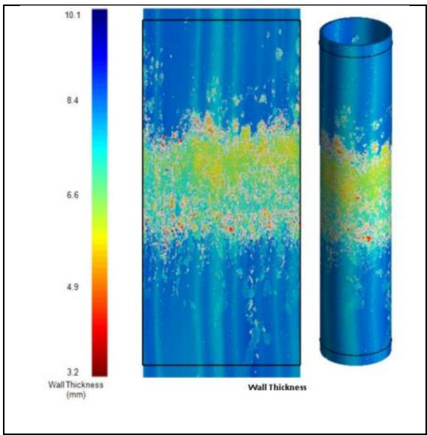	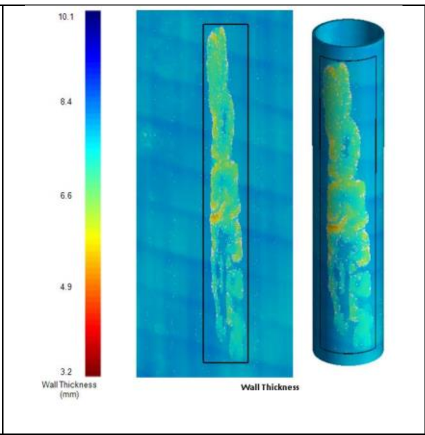	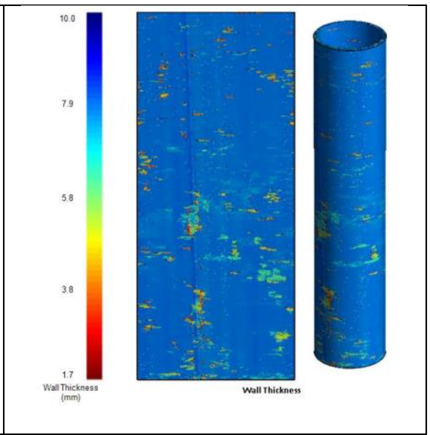
4a. Band corrosion	4b. Strip corrosion	4c. Pitting corrosion

Figure 4: Examples of different corrosion types

4. OPERATIONAL LEARNINGS

With the QWIX tool being a new service offering, some learnings were developed during the campaign.

As noted above, the QWIX tool requires a liquid medium to operate. Procedures were in place to ensure the wells were filled prior to the logging operation commencing. On one of the early wells, once the log had been completed and tool retrieved, during the quick look of the data, it was observed that approximately the top 5 m of the well had not been logged due to the fluid level in the well dropping while the log was being conducted. The speed of retrieving the tool and accessing the data meant that the well could be re-filled and upper section re-logged to obtain the missing data while all crews and equipment were still on location. Based off this event, an additional step was added to the job procedure. Now, as the QWIX tool is approaching a depth of 150 m, the Quest supervisor notifies the rig crew so they can confirm the fluid level is still at surface, topping up as required.

5. ENGINEERING EVALUATIONS

5.1 Corrosion Rate Assessment and Risk Review

The data obtainable by a QWIX log, especially if multiple time spaced logs are performed, allows operators to understand their well environments, corrosion growth rates and risk profiles. Development of a corrosion prediction model is possible to enable forward planning and identifying fields, or areas, with the most aggressive corrosion. These models can then be used to conduct corrosion risk reviews, identifying patterns between well, formation and corrosion damage. Once the corrosion mechanisms and field conditions are understood, risk ranking of the fields can be performed to allow for specific targeting of the most at risk of corrosion wells.

5.2 Fitness for Service

By utilising the data obtained during a QWIX log, a detailed Fitness for Service analysis of the casing can be conducted according to API 579. This provides the operator with assurance that their well has the required integrity to continue operation, notifies them that remedial work will be required to maintain or regain well integrity, or that the well may need to be abandoned if no suitable remediation options are available.

6. GEOTHERMAL WELLS APPLICATION

Standard procedures for assessing well condition in geothermal wells is generally by use of a multi-arm mechanical calliper and/or pressure, temperature, and spinner (PTS) tools. Standard high temperature multi-finger callipers are available to provide estimates of internal corrosion (Marbun et al., 2019). A high temperature multi-arm mechanical calliper with electromagnetic sensors marketed as the High Temperature Casing Condition (HTCC) tool is also available to measure casing thickness and internal diameter (Clements et al., 2019). With 60 fingers and a maximum pipe size of 14 in, the sensors on the fingers are able to accurately assess approximately 45% of the inner casing surface on a 14 in, 82.5 lbf casing with internal diameter of 12.996 in. This low level of accuracy was noted when the HTCC did not identify a production casing leak in a well with a reported integrity issue that had to be verified with an additional camera run (Clements et al., 2019). The QWIX tool provides much more detail and accuracy then these conventional tools, measuring 100% of the casing surface. Use of PTS tools is purely a qualitative measurement, providing general indications of a potential problem, and only while a problem is occurring, i.e. while a well already has a casing hole and fluid is escaping. The QWIX tool offers the opportunity for proactive actions to assess casings before there is a well integrity breach. Setting packers and pressure testing the casing have also been used to try and estimate locations and extent of casing corrosion issues (Thorhallsson, 2003). While proving a well leak, these pressure test assessments give no information on the extent of the problem, or if other leaks are likely to occur.

The Health and Safety Guidelines for Shallow Geothermal Wells Systems guideline from Worksafe (Worksafe New Zealand, 2018b) specifies that "… outer casings shall be monitored for corrosion and deterioration…", the QWIX service allows for potential extension of that monitoring to include inner casings at deeper depths. By providing assurance of integrity across the entire wellbore, operators can be assured they are not losing heat to the surrounding formation. Casing corrosion has been identified as a common cause of leakage in geothermal wells (Marbun et al., 2019). Casing failures in geothermal wells due to corrosion have been identified as issues within 2 years of wells starting production in fields with low pH production fluids, with external casing corrosion seen after 5 years (Southon, 2005).

The guidelines from Worksafe (Worksafe New Zealand, 2018b) also state "*Where casing inspection reveals that severe corrosion is evident on the near-surface production casing, the production casing shall be exposed until sound casing is revealed. The well shall be quenched prior to cutting off the damaged casing and welding on a new section and wellhead flange."* This is exactly the actions that a coal seam gas operator is taking with a well logged by QWIX. A through wall hole was identified by the QWIX at a depth of 2.3 m below surface. The operator is temporarily suspending the well, excavating around the casings to below the depth of the hole. They will then remove the external 14 in and 9 7/8 in casings, then cut off the 7 in production casing below the through wall hole. The well head will then be reinstalled in a permanent position below ground level.

It is not unusual for geothermal fields to have high levels of CO_2. The presence of CO_2 can greatly increase the rate of casing corrosion, forcing early abandonment of wells. A number of wells in the Imperial Valley in California suffered from CO_2 corrosion, of up to 3 mm per year, and required abandonment after only 10 – 12 years (Allahvirdizadeh, 2020). Therefore, it is prudent for geothermal operators to have a well integrity monitoring program in place that allows them to ensure the security of their wells, be able to forecast well integrity issues and plan for end of well life, rather than waiting for wells to fail before taking action. A proactive approach proves to regulators, and the community, that well integrity is taken seriously. Geothermal wells are also more likely to experience internal corrosion when casings are exposed to hot brines and acids. This exposure can reduce well life by increasing the rate and extend of wall loss in exposed sections.

The QWIX tool requires a liquid medium to operate. As such, wells will require quenching prior to any logs being performed, the same as electrical calliper tools. Timing of logs can be planned to coincide with other well operations that also require quenching, so as to minimise the impact on the well from excessive quenching. The log is not impacted by the properties of the fluid and there are no density or rheology limitations. Anti-scalant systems within geothermal wells are not compatible with QWIX and would inhibit its ability to acquire full circumferential data on the casing. Timing any QWIX logs with other well operations that would involve quenching the wells and removing anti-scalant systems would be the recommended approach, to limit well downtime and reduce the total cost of the log. A regular well condition monitoring program has been recommended for geothermal wells (Clements et al., 2019), to enable early identification of well integrity problems. Incorporating a regular QWIX log into these programs would allow for monitoring of corrosion and assessment of corrosion growth rates. This information can be valuable to operators as it would allow them to take pro-active steps in future planning for which wells ~~that~~ need extra monitoring, or planning for when wells need to be decommissioned.

In its current iteration, the maximum recommended operating temperature of the tool is approximately 65°C. This will require cool fluids to be pumped into the well and logging to occur as soon as practical. If the fluid level in the well requires continual topping up, the constant injection of cool fluid can assist in maintaining the well within the temperature limits of the QWIX tool.

7. CONCLUSION

The introduction of the QWIX logging technology to upstream wells has resulted in a new level of insight for Operators. The data provided during the referenced campaign has allowed the Operator to improve their understanding of well corrosion in their fields and demonstrate a proactive approach to well integrity to the Government body responsible for petroleum resource activities. Throughout the campaign, learnings were identified by Quest field teams to optimise the work procedures and establish tool reliability. Operational learnings were also identified and shared with the client to improve efficiency and reduce rig time.

Trials with a number of clients have proven the accuracy, speed and value of QWIX. Comprehensive and detailed analysis of casings was achieved due to high resolution data acquisition, with typically over 2 million data points per log. Ongoing, long-term campaigns with QWIX are becoming a valued service in the upstream wells sector. It is envisaged that repeat logs in the future will enable clients to accurately assess rates of casing corrosion, which will provide valuable data for developing corrosion growth models and predicting the risks of well integrity failures. Future work to combine QWIX logs with cement bond logs to validate influence of cement integrity on casing corrosion is ongoing to provide enhanced value.

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