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The Use of Corrosion Resistant Alloy to Address Erosion Corrosion Problem in a Well in Mt. Apo Geothermal Field, Philippines

Jo-Ann Ritch B. Camba, Mark Angelo O. Malibiran, Rhemal Jay T. Tamboboy, Kenneth S. Faja, Benson G. Sambrano and Gabriel M. Aragon
Energy Development Corporation, One Corporate Center, Julia Vargas cor. Meralco Ave, Ortigas, Pasig City, Philippines
camba.jrb@energy.com.ph

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ABSTRACT

Mt. Apo Geothermal Field, Philippines has been producing 104 MW from two (2) power plant units since 1997. At the onset of production, most of the geothermal wells are discharging near neutral fluid. In year 2013, a new well was completed which discharged erosive-corrosive fluids. The new well has a pH of 2.0 and total suspended solids of about 15 mg/kg. Both the branch-line and wellbore casing were severely damaged with complete penetration in just three (3) months of continuous discharge.

This paper presents the results on the use of corrosion resistant materials to address the erosion corrosion problem in both wellbore and surface facilities of the new well. The CRA liners are shown to be in good condition based on downhole survey. The wellbore CRA's usable life is calculated to last up to 25 years. As for the above ground facility, a stainless steel wellhead separation system (WHSS) was installed to isolate the erosive-corrosive discharge fluids from the existing facility. Based on the measurements conducted, no significant damage is noted in the wellhead separation system. To monitor effectiveness of the CRA materials, regular ocular inspections and caliper inspection surveys are being done.

1. INTRODUCTION

Mt. Apo Geothermal Project (MAGP) is located in the southern part of the Philippines contributing 104 MW to the national grid. The geothermal field has a concession area of 701 hectare. Production stage started in year 1997 with wells discharging near neutral fluid. Erosion-corrosion issue was not yet a problem at the onset of production in 1997 up to Y2012.

In year 2013, well A6 was a newly drilled well which discharged initially slightly acidic fluid with pH 4.1-4.3. But its acidity gradually increased to pH 2.5 after a month of discharge. In less than 3 months into its production, a pinhole leak developed at the production tee. Casing Inspection Caliper (CIC) (Figure 1) and Down-hole Viewer (DHV) (Figure 2) surveys confirmed >60% even up to 100% penetration from Casing Head Flange (CHF) to end of build up at 645 mMD. Following the foregoing downhole results, well A6 was temporarily cement plugged to contain the risk of a potential well blowout.

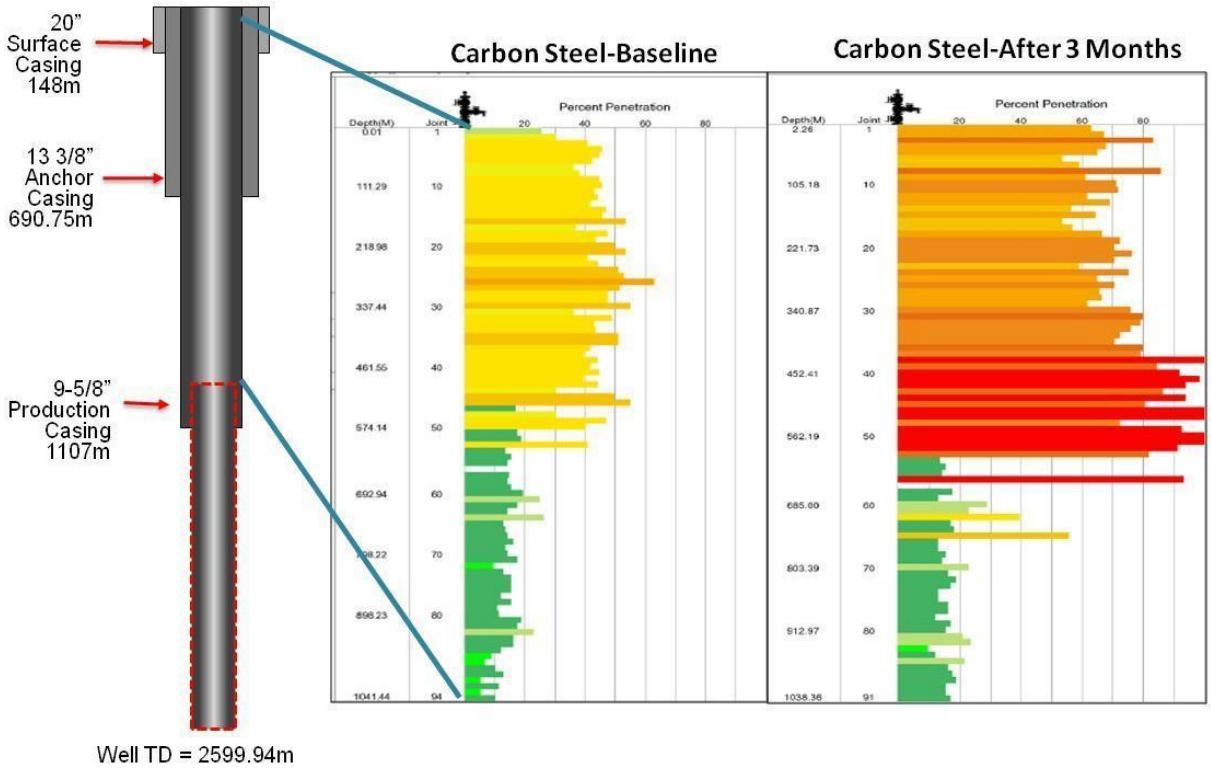


Figure 1.Casing inspection caliper results of carbon steel liner-baseline and after 3 months

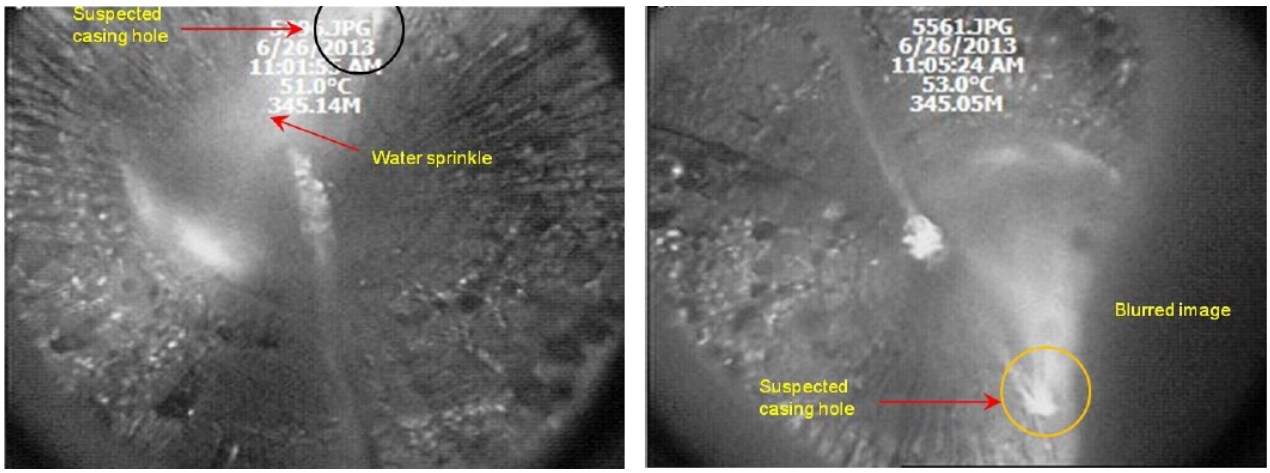


Figure 2.Downhole viewer image of carbon steel liner after 3 months exposed to corrosive fluid

Well A6 was worked over and relined with 7" CRA casing from CHF to 963.74 mMD on June 17, 2014 and initial discharge testing to the silencer began on August 7, 2014. The well was subjected to several discharge tests in August 7-October 8, 2014 and in March 9-May 1, 2015. The objectives of discharge testing to the silencer are (1) to fully characterize the chemistry of the well, (2) to determine suitability of relined CRA, (3) to identify the surface facilities needed to cut-in the well. And each test completion are accompanied with downhole surveys to examine the CRA liners. After the comprehensive data gathering during discharge tests, Well A6 was cut-in using well-head separation system to the existing two phase line header in February 25, 2016.

The paper aims to discuss the information gathered and challenges encountered during the discharge tests and commercial operation of Well A6. Data such as chemistry, CIC of CRA casing, DHV of casing, corrosion rates, ocular inspections at the surface and challenges encountered during commercial operation are included in this paper

2. CONDUCT OF THE STUDY

Baseline casing inspection caliper (CIC) and downhole viewer surveys were performed after the 7 inch diameter CRA casing were run in to get baseline data. After the discharge tests, CIC of CRA liner was carried out to evaluate the performance of CRA and estimate the casing life.

Material testing for the suitable above ground facility was determined by using Electrical Resistance (ER) probe. Materials tested are Stainless Steel and Inconel. Thinning rate criteria for the above ground facility is 0.12 mmpy or 3 mm metal loss for 25 years. The acceptable CRA material based on the foregoing criteria was used in the Well Head Separation System (WHSS).

The chemical parameters monitored to determine the erosive-corrosive property of the well were pH, Fe, Cl, SO_4, TSS levels. Ocular inspections were conducted to document mechanism of damage and establish failure sections in the materials used during discharge testing and in the WHSS.

3. RESULTS AND DISCUSSION

3.1 Discharge Chemistry

At its initial discharge, Well A6 is less acidic at pH 4.5, and its pH gradually decreases to pH 2.5 causing leak and prompted to shut the well in Apr. 2013. Also at that time, major chemical parameters like Silica, Chloride and Sulphate are not yet stable and still at increasing trend (Figure 4). Iron level is at ~250-400 mg/kg accompanied with very high TSS at ~800-1600 mg/kg (Figure 3).

Post CRA relining in Y 2014, two discharge tests to the silencer are conducted in Y2014 and Y2015 and it was observed that pH stabilized at pH 2.0. Iron level also dropped to ~100-200 mg/kg and TSS significantly dropped to ~5-25 mg/kg compared to its initial discharge. On its discharge test#1 to the silencer in Aug-Oct 2014, Well A6 chemical parameters like Silica, Chloride, and Sulphate are not yet constant because of frequent carbon steel pipe leaks at the surface disturbing continuous well discharge. On its second discharge test to the silencer in Mar-May 2015, the chemical parameters are relatively stable compared to previous data after carbon steel test gears are changed with stainless steel.

In Feb 2016, Well A6 was cut-in to the existing two phase line header. The well A6 corrosive property is apparent with pH at 1.9-2.0. Iron level initially at ~200 mg/kg eventually stabilized at ~50 mg/kg, which is the reservoir Fe content while the excess at initial discharge might be the Fe of casing material. Its TSS level is maintained at ~5-25 mg/kg (average at 15 mg/kg). Silica concentration seem to be constant at 1000 mg/kg, while Chloride and Sulphate showed an increasing trend at the later part of Y2018 to Y2019 which might be indicating a new reservoir process happening.

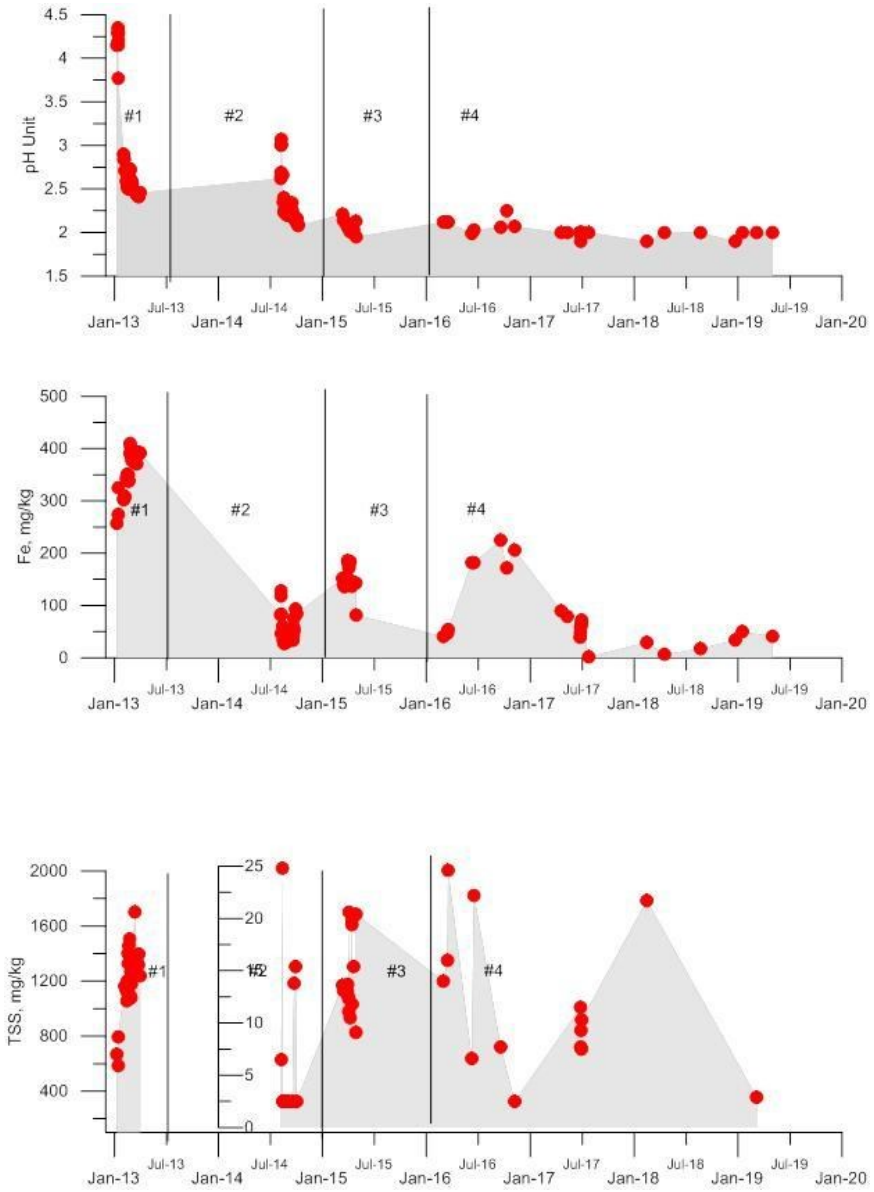


Figure 3. Chemistry data (pH , Fe, TSS). Legend: #1- First discharge of the well on Jan-Apr 2013; #2- Discharge test#1 to the silencer post CRA (Aug-Oct 2014); #3- Discharge test #2 to the silencer post CRA (Mar-May 2015); #4-Commercial operation (Feb 2016-present)

Sulphate concentration is emphasized in this section because Well A6 has the highest Sulphate concentration (~3000-6000 mg/kg) in Mt Apo field compared to the main brineline sulphate concentration which is at 50-100 mg/kg (Figure 4). Well A6 acidity is controlled by sulfuric acid as bisulphate with ionization constant of Ka2=1.3X10-2; which is equivalent to a buffering pH value of 1.886 (pKa2). pH of Well A6 is 1.9-2.0 at 25 deg C.

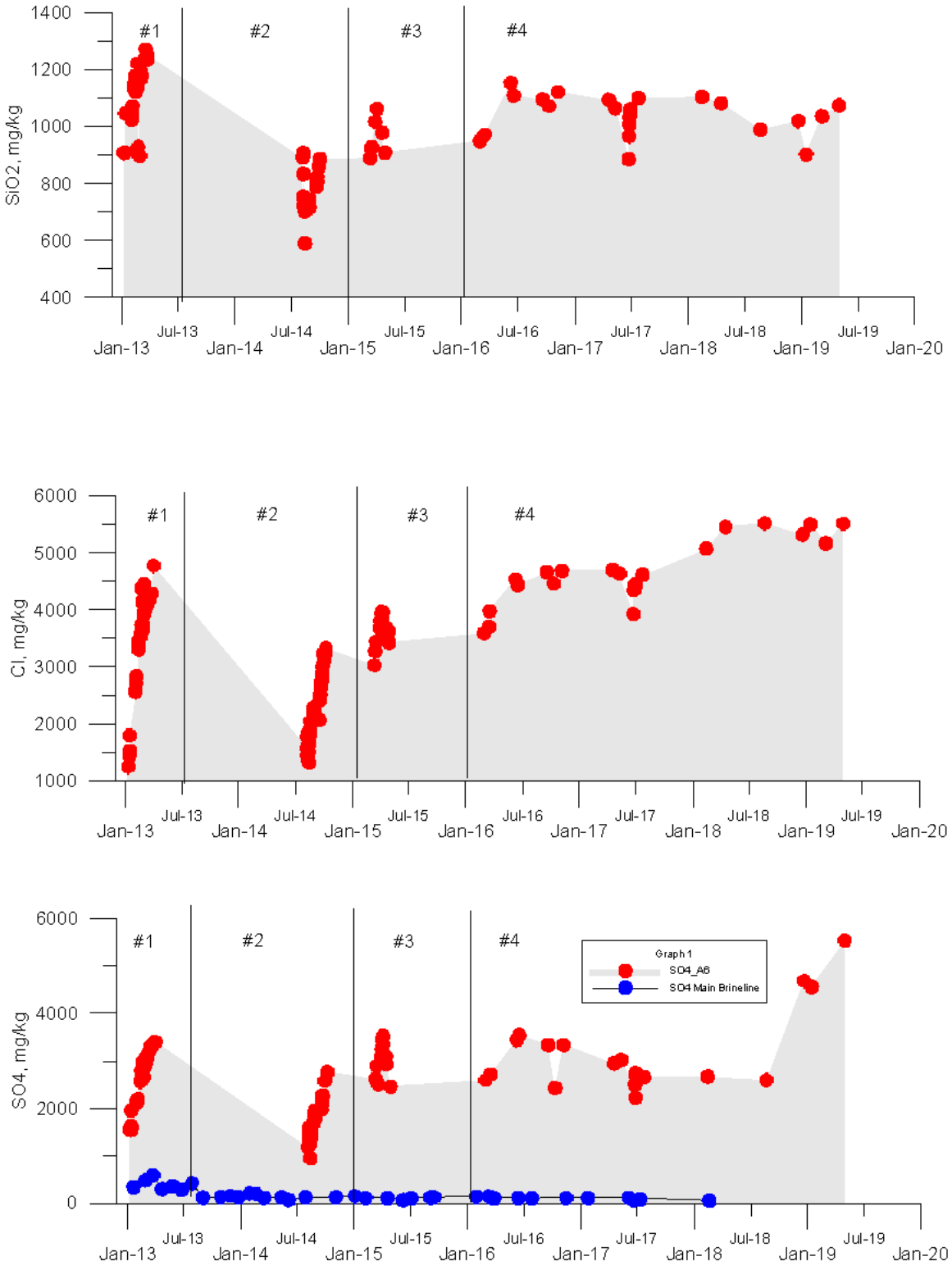


Figure 4. Chemistry data (SiO2, Cl, SO4). Legend: #1- First discharge of the well on Jan-Apr 2013; #2- Discharge test#1 to the silencer post CRA (Aug-Oct 2014); #3- Discharge test #2 to the silencer post CRA (Mar-May 2015); #4-Commercial operation (Feb 2016-present)

3.2 Casing Inspection Caliper (CIC) Result of CRA liners

Baseline caliper survey (CIC#1) was conducted after CRA was run-in in year 2014 (Figure 5). Based on the CIC results, the condition of the casing surveyed appeared to be in good condition with respect to corrosion and mechanical-related damages. The deepest penetration noted was 16.6% of the casing wall thickness which is suspected to be inherent in the casing. Subsequent CICs were performed after discharge test to the silencer in Y2014 and Y2015 where the CRA liners were exposed to the discharge fluids for 38 days and 82 days, respectively. Based on the Y2014 (CIC#2) and Y2015 (CIC#3) results, majority of the joints surveyed have penetrations below 20%. The casing surveyed appeared in good condition with respect to corrosion-related damage. These penetrations may be an inherent property of the pipe based on the defect codes accepted by the National Association of Corrosion

Engineers (NACE), where penetrations below 20% are considered intrinsic defect of the casing. The calculated usable life at the critical zone is 25-27 years.

Having confidence in the integrity of CRA liners, Well A6 was cut-in to the existing two-phase line header from Feb-Jun 2016 as part of the observation period. On June 30, 2016 after about 3 months of continuous discharge, CIC#4 was performed. Unfortunately, the wireline snapped at the surface during the CIC survey, hence the survey depth reached only up to 376 m due to fish-in-hole (FIH). A comparison between the most recent and previous downhole surveys indicates no increase of corrosion-related damage. With good casing integrity, Well A6 was utilized as a regular well

Then on June 19, 2017, after one year utilization, CIC#5 was performed. Based on data, the condition of the casing appears good with respect to corrosive damage. The deepest penetration recorded is 0.07 inch located at 33.7m which measures 19.3% and considered intrinsic defect of the casing wall thickness. Thinning rates at critical zone and below critical zone based from maximum recorded penetration is 0.011 inches per year and 0.010 inches per year. Estimated casing life at critical zone is 22.8 years and below critical zone >25 years.

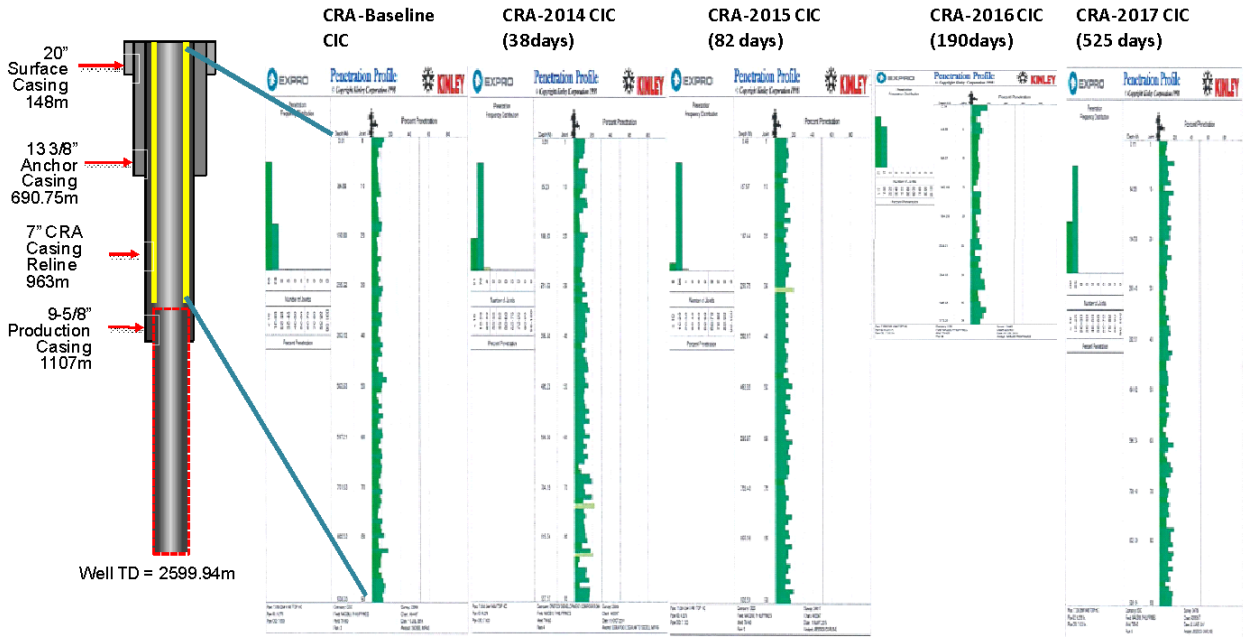


Figure 5. CIC results of CRA liner

3.3 Down-hole Viewer (DHV) Image of CRA liners

Down hole viewer survey was done in June 2014 after CRA was run in. Downhole images showed that the CRA liners are in good condition (Figure 6). Minor scratches are observed which may be attributed to the run-in and pull-out of downhole clearing tools.

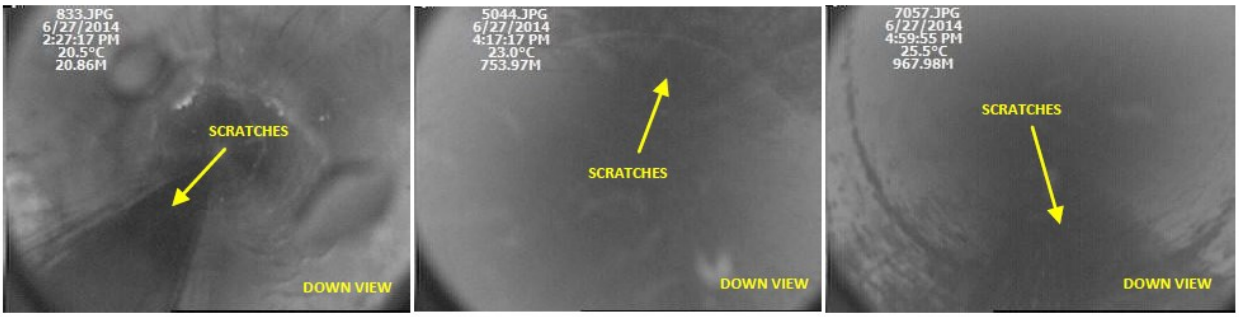


Figure 6. DHV image of CRA as baseline-after run-in

Another DHV survey was conducted in Nov 2014 after 38 days of discharge (Figure 7). DHV image of CRA after 2014 discharge test with little or no corrosion-related damage. In June 2016, a DHV survey was conducted to evaluate the fish in hole. CRA casing are also seen in the DHV and shown to be in good casing condition (Figure 8). With these findings, DHV survey was set as contingent to CIC. DHV will only be performed when CIC result showed significant penetration to the CRA wall casing.

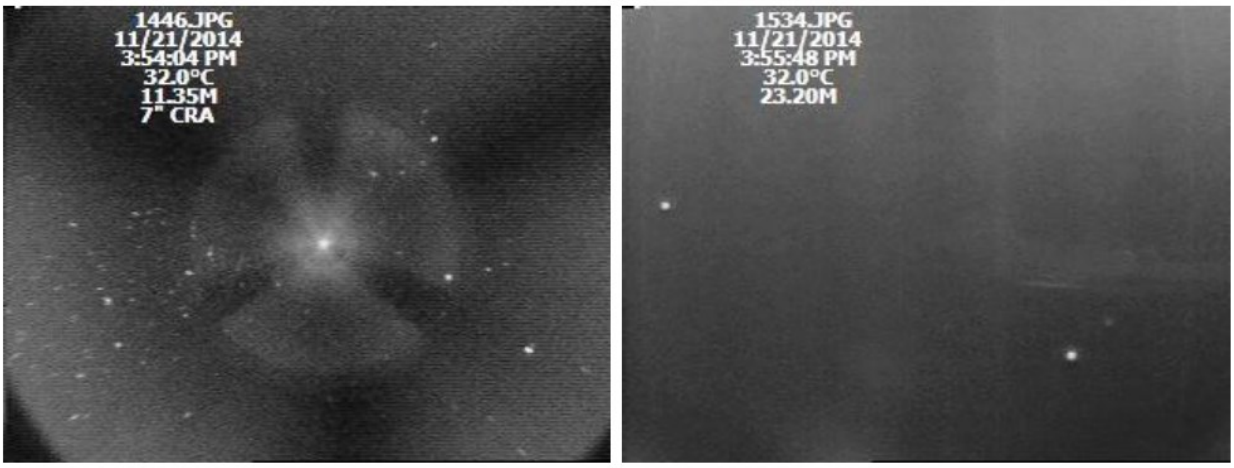


Figure 7. DHV image of CRA after 2014 discharge test

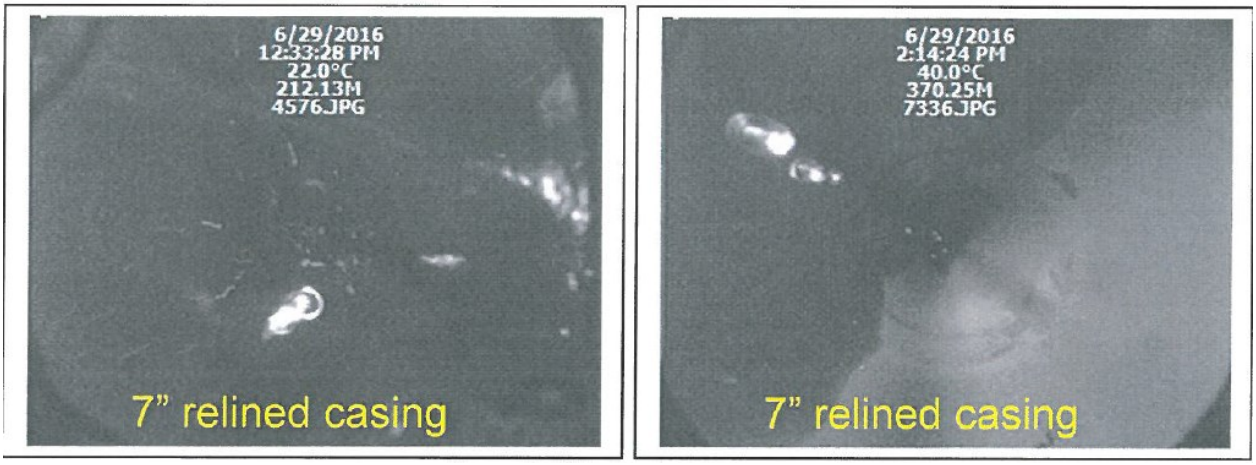


Figure 8. DHV image of CRA (June 2016)

3.4 Corrosion Rates for the Branchline

To determine the suitable material as branchline, corrosion resistant materials such as Inconel and Stainless Steel Electrical probes are inserted in Well A6 pipeline. Inconel initially indicates a high corrosion rate at about 9 mm per year; but rapidly stabilizes to 0.05 mmpy (Figure 9) as soon as the perceived passive film has developed. The average corrosion rate at stable thinning rate is 0.10 mmpy, which is acceptable and within the desired ≤0.12 mmpy.

For the Stainless steel, the initial corrosion rate is also high at 3.5 mmpy and stabilizes at 0.03 mmpy (Figure 10). The average corrosion rate from the stable data is 0.06 mmpy, which is acceptable for branch-line use based on the criteria ≤0.12 mmpy (that is equivalent to removing 3 mm of the material for 25 years).

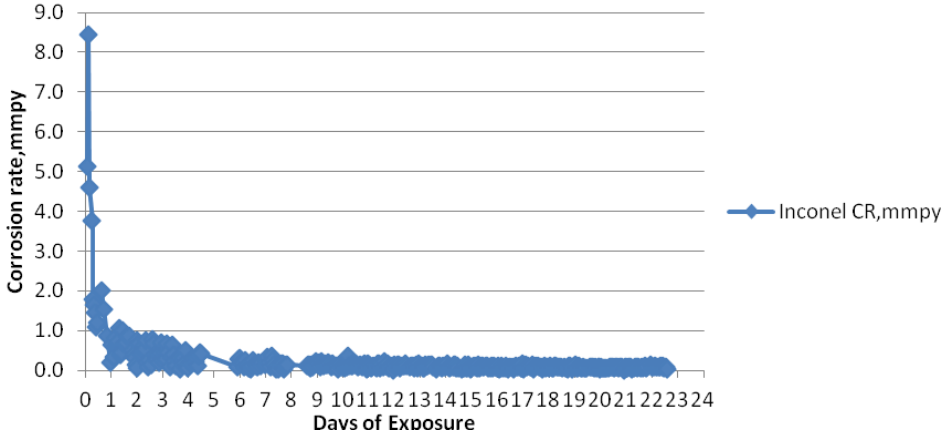


Figure 9. Inconel corrosion rate

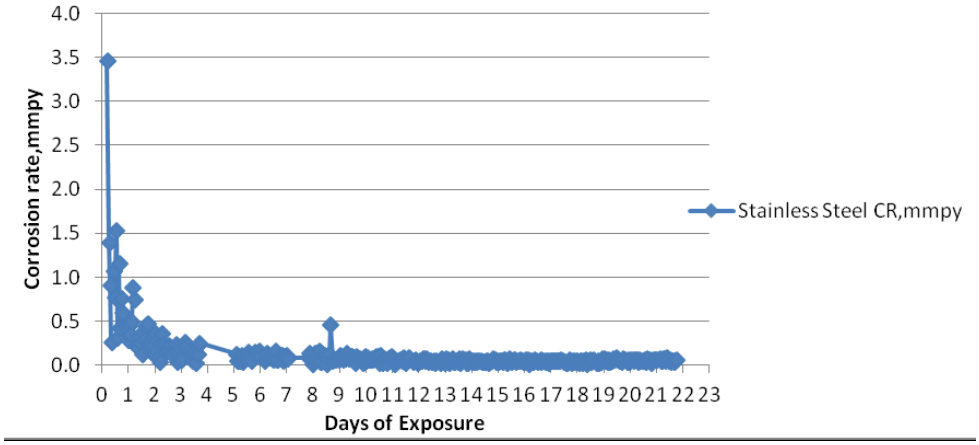


Figure 10. Stainless steel Corrosion Rate

3.5 Ocular Inspection of Well Head Separation System

Well head separation system (WHSS) (Figure 11) was utilized to protect the existing two phase line header from the corrosive fluid of Well A6. Two phase fluid from Well A6 travels through a stainless steel branchline and goes to a stainless steel cladded separator. Only the steam of Well A6, which has a pH of ~4.5, is introduced into the two phase header. And its brine is being flashed into the atmosphere via brine diffuser. As part of due diligence before commercial operation, the WHSS was inspected by a material scientist. He recommended that the WHSS is a suitable set-up.

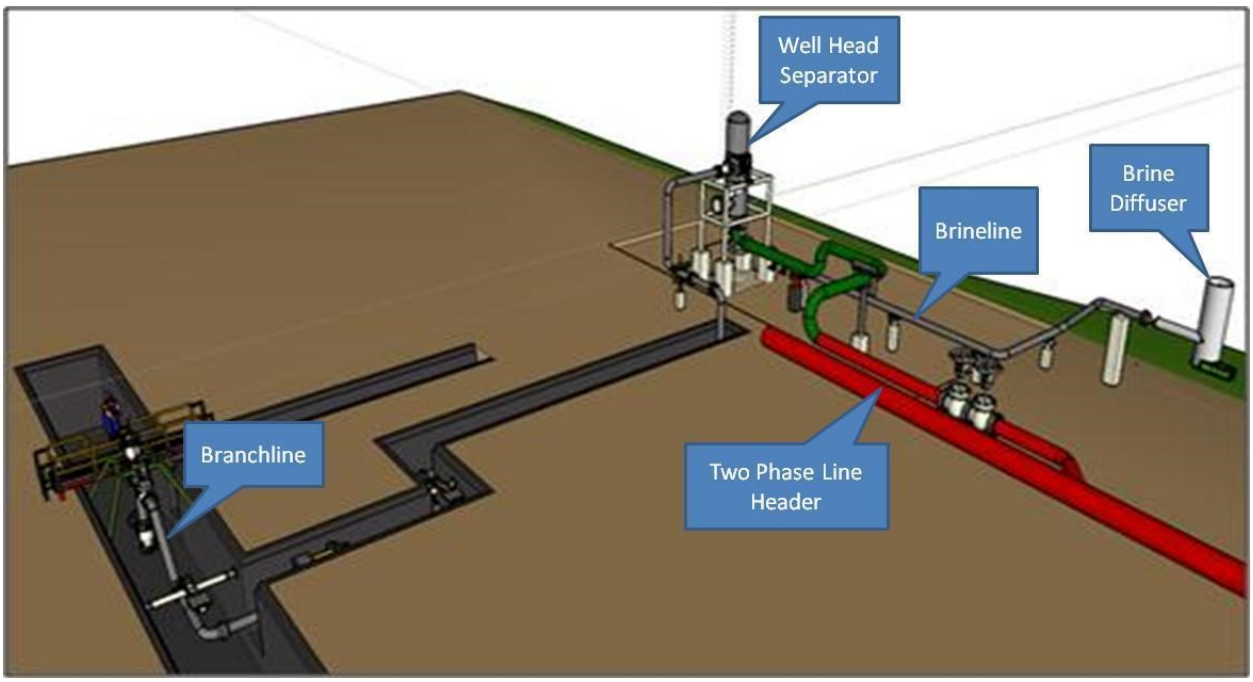


Figure 11. Well A6 Well Head Separation System (WHSS)

Ocular inspections made at the stainless steel side valve revealed very little to no corrosion damage as documented (Figure 12). Thickness of WHSS is monitored using Ultrasonic Thickness Gauge (UTG). Corrosion rate (CR) of stainless branchline is 0.4-1.1 mmpy, stainless steel brineline is 0-0.73 mmpy and carbon steel steamline is 0.4-1.8 mmpy. Although CR absolute values are high in terms of mmpy, no significant damages were noticed during ocular inspections of the WHSS. Regular UT measurements were programmed to monitor the corrosion rate and anticipate necessary pipe replacement.



Figure 12. Ocular inspection at Well A6 Stainless Steel Branchline

3.5 Challenges Encountered during Commercial Operation

Well A6 is commercially cut-in to existing two phase line header since February 2016. Well utilization record is plotted in Figure 13. Well A6 operation has been permanent except for some leak occurrence at the surface facility. Episode of well A6 being out of service happened in April 2017 when a pinhole leak at the steamline occurred (Figure 14). Mechanism of damage in the carbon steel steamline is attributed to pitting corrosion caused by brine carry over. At the moment, elbows of the carbon steel steamline are cladded with hard material to prevent break out recurrence.

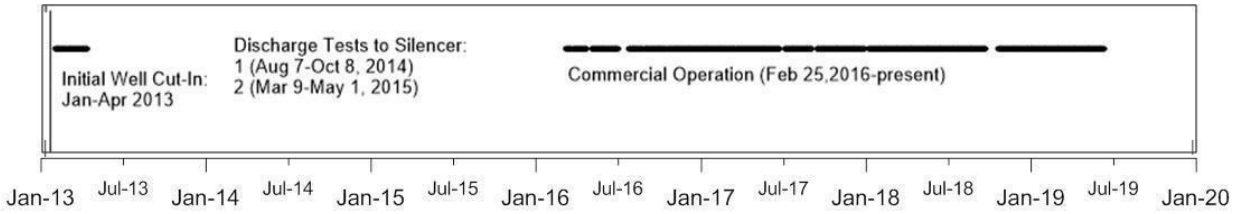


Figure 13. Well A6 utilization record

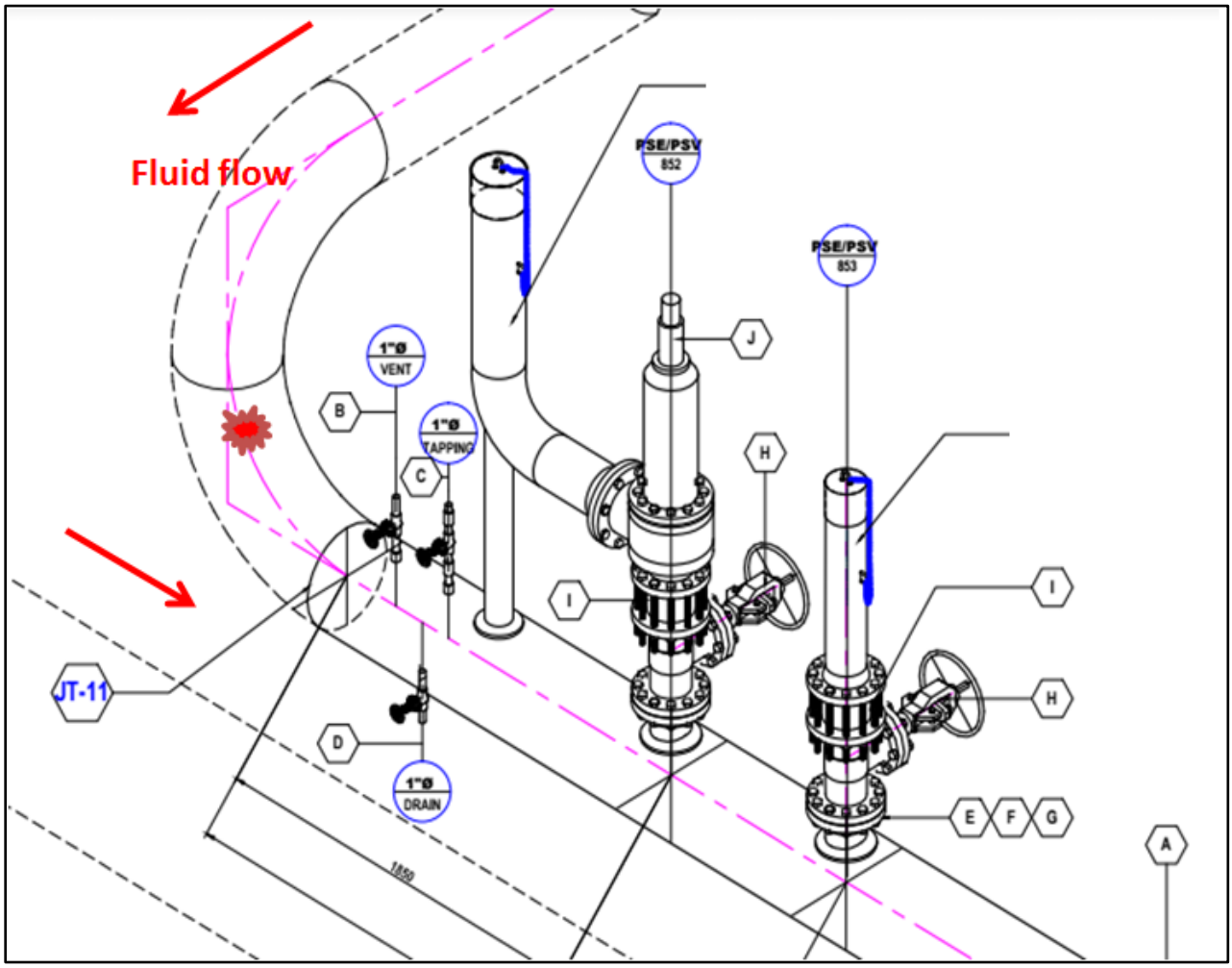


Figure 14. Leak occurrence at Well A6 WHSS steamline

4. CONCLUSION

The CRA casing is effective and able to withstand the erosion-corrosion of Well A6. CRA can extend the useable life of casings to 25 years or more. The use of WHSS isolating the aggressive fluids from the existing two phase line header has been a good set-up having no incident of header shutdown since well A6 was cut-in. The use of stainless steel as pipe material is an appropriate selection which enables continuous utilization of the well. There will be a regular caliper survey programmed to monitor the CRA casing performance. For the above ground facility, regular UT measurements and ocular inspections of the WHSS are being done to monitor corrosion.

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