RESTORING WELLBORE INTEGRITY IN A COLD BRINE AND CONDENSATE INJECTOR, MAK-BAN GEOTHERMAL FIELD, PHILIPPINES

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ABSTRACT

Bul-25 has the second highest capacity of five cold brine and condensate injection wells located in the Mak-Ban Geothermal Field, Philippines. Cold brine and condensate are mixed together in a single injection system (CBCIS); the condensate component of the stream is found to cause corrosion along the surface piping and also in the wellbore casing. To protect the integrity of the cemented 9 ⅝ in (244.5 mm) casing, a 7 in (178 mm) hangdown liner was installed in Bul-25 in 1987. As part of the wellbore integrity monitoring program of steam field operator, Philippine Geothermal Production Company, Inc., casing inspection caliper (CIC) surveys were regularly conducted on Bul-25. In 2011, the CIC indicated a casing hole on a shallow portion of the hangdown, along with signs of significant corrosion and pittings elsewhere along the hangdown. The well was placed in the 2017 workover program to replace its hangdown with a cemented secondary tieback casing.

During the workover, the hangdown liner was retrieved in separate sections due to its condition. Additionally, visual inspection of the liner during the pull-out confirmed the findings of the 2011 CIC survey, with sections of severe corrosion found throughout the string. A total of 2110 ft (643 m) of hangdown liner was successfully extracted and 55 joints of 7 in (178 mm) casing were run and cemented afterwards.

An injection capacity test performed after the cementing of the new tieback using 2 rig pumps and a cementing unit showed that the well accepted 24 bpm (3.84 m^3/m) for a total testing time of 28 mins. Two weeks after the workover, Bul-25 was successfully re-commissioned as a cold brine and condensate injector with its wellbore integrity fully restored and no changes to its previous performance.

1. INTRODUCTION

The Mak-Ban Geothermal Field (Mak-Ban) is located in Bay, Laguna, and is 75 km south of Metro Manila. Philippine Geothermal Production Company, Inc., a Filipino corporation, holds the exclusive rights granted by the Philippines Department of Energy in 2013 to operate the geothermal steam field facility for 25 years, and to provide steam to third-party owned power plants**.** Situated in between the mountains Mt. Makiling and Mt. Banahaw, Mak-Ban has 65 production wells and 16 injection wells and an installed capacity of 478 MWe. There are two injection systems that are run within Mak-Ban, one for hot brine and another for combined streams of cold brine and condensate.

The Cold Brine and Condensate Injection System (CBCIS) (Figure 1) is a network comprised of 5 injection wells with the function of disposing cold brine from the satellite station sumps and condensate from the power plants. Because of the acidity of the fluid and also due to injecting wellhead pressure at vacuum with air and oxygen carried over by the fluid, the injection wells that are hooked up to this system are closely monitored for any well integrity issues.

Bul-25 is an injection well commissioned to CBCIS, and will be the subject of this case study. It is located at the Southwestern portion of the Mak-Ban Geothermal Field (Figure 1). Drilled in 1978, it is currently the second largest cold brine and condensate injector, with a capacity of 550 kph (250 t/h) at 69 psi (0.48 MPa) injecting well head pressure (IWHP) (Aquino, 2010)**.** As an experiment to test the corrosive properties of the injectate, a hangdown string with corrosion coupons was run in 1987, 9 years after its original drilling. After two months, a CIC survey was run to check for corrosion. Multiple grooves caused by corrosion were seen in the results, which confirmed the process fluid's corrosive properties. Corrosion was also found to be occurring where the water level was located. After the experimental liner was pulled out and inspected, a new hangdown liner was run as it was concluded that despite the presence of corrosion, the liner was still sufficient to preserve the integrity of the cemented 9 5/8 in (245 mm) production casing of the well.

In 2011, the well's hangdown liner was showing signs of corrosion based on CIC results. It was decided to include the well in the 2017 work-over program, and the hangdown liner was replaced with a secondary tieback casing to permanently mitigate the presumably poor condition of its original production casing.

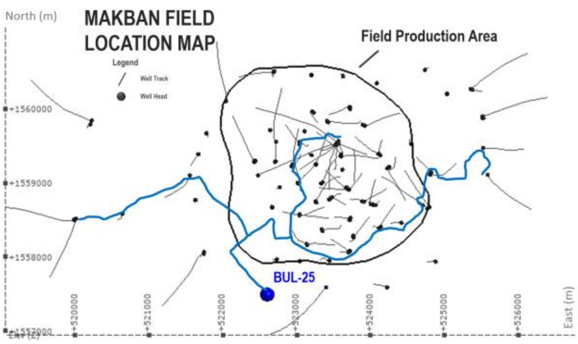

Figure 1: The Mak-Ban Cold Brine and Condensate Injection System (CBCIS), traced in light blue. The location of Bul-25 is marked accordingly.

2. WELL INTEGRITY MONITORING

The operation of a geothermal field is most commonly associated with managing steam and brine flow while generating power efficiently. However, an aspect that is of equal importance is monitoring well integrity. It can be classified into two categories: wellbore integrity and wellhead integrity. For the purposes of this case study, the focus will be on the former.

Multiple well and reservoir properties are considered when analyzing wellbore integrity, including maximum cleared depth (MCD), remaining wall thickness, the presence of deformations, corrosion, pitting, casing collar gaps/damages, clay cap location, fracture gradient, and reservoir pressure. These aspects will give an overall picture on the specific condition of a well, and will determine if a workover is needed to maintain safe operation. To accurately and precisely measure wellbore condition, surveys are available for the field operator to choose from, namely: casing inspection caliper (CIC), downhole video (DHV), scale probe, and high temperature casing condition (HTCC).

Because of the simplicity of its operation and the need to run multiple surveys in a year, the CIC is the tool most commonly used by PGPC.

2.1 Casing Inspection Caliper

There are two types of CIC tools that are normally run in PGPC wells – a 30-arm Kinley Mega Data Caliper (Figure 2) with high sensitivity designed for detecting more localized thinning and/or pitting, and the 15 arm Kinley Baseline Caliper as an alternative when the wellbore is slightly restricted. For increased circumferential coverage of the wellbore, the 30-arm tool is preferred and is used for most surveys. However, for this case study, the Kinley Baseline Caliper was used due to the small internal diameter of Bul-25.

Figure 2. A Kinley Mega Data Caliper.

When the CIC is run, production and injection wells are shut-in to minimize vibrations caused by flowing steam or injected brine that may lead to questionable results. Furthermore, this is also to ensure that the tool is not subjected to high total mass flow rates, which may cause damage and even lead to a lost-in-hole incident.

CIC surveys are run only until the top of liner (TOL), which is the section of casing that meets the perforated liner. It may also be ran on casing modifications such as hangdown liners and scab liners.

When a survey is completed, the results are analyzed and sent to PGPC by a third-party contractor. The processing of raw CIC data is not done by PGPC engineers since the equipment required for this is not available in-house. On the other hand, the analysis of the processed data is reviewed in-house by drilling engineers, as well as reservoir engineers for additional input. In PGPC, it is standard to conduct CIC surveys every five years, especially on active wells such as producers and cold brine/condensate injectors.

2.2 CIC Analysis Procedure

CIC results give a good overview of a well's wellbore integrity. From the maximum deflection felt by the calipers' fingers, the minimum wall thickness (MWT) of the analyzed casing can be determined. As per PGPC standards the minimum allowable casing wall thickness is 0.2 in (5 mm) as the first pass of filtering the MWT, which is from tri-axial stress analysis based on a shut-in wellhead pressure of 1000 psi. Any section of the wellbore that falls below this standard is considered below minimum allowable thickness (BMAT). Furthermore, another criteria for determining the criticality of a reading is the depth at which it is located. A standard, called the depth of overburden, approximates the ability of the formation around the well to contain possible fluid release that may come from casing holes. Using the reservoir pressure and fracture gradient, the depth can be calculated with the equation below:

$$h_{overburden} = \frac{P_{res,max}\ x\ FOS}{fracture\ gradient}$$

For Mak-Ban, the resulting depth of overburden is approximately 1000 ft (304.8 m) (Haas, T. R.; Rivera, N. N.; Barcelon-Minguez, E. A., 2000); thus, any casing holes or sections of corrosion located above this depth are considered critical. A more detailed analysis of the well integrity can be performed to further characterize the criticality of the condition by identifying, for example, the depth of the clay cap encountered by the well.

Aside from MWT, a list of the notable deformations and pitting found along the wellbore are shown to aid the analyst in pinpointing depths of concern. It is worth noting that casing sections which are BMAT are most likely going to be present in this table. Additionally, both percent penetration and metal loss profiles are given to spot casing holes or sections of corrosion, respectively. Figure 3**Error! Reference source not found.** below is an example of a penetration profile representing a casing in good condition.

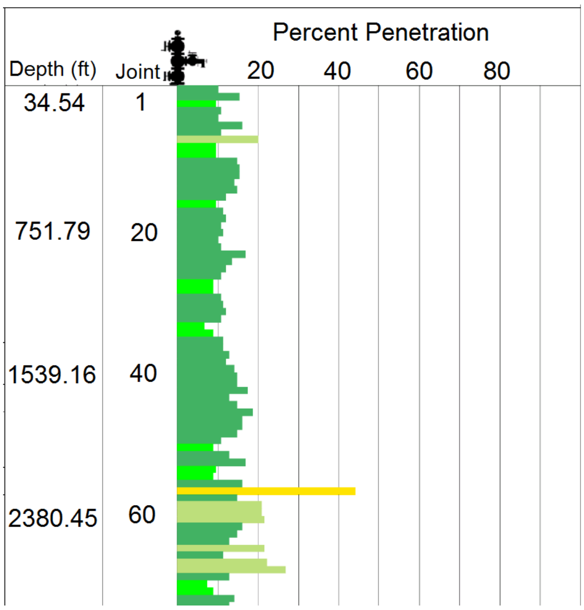

Figure 3: A well's penetration profile showing good casing condition.

The last section of the report is a visualization of the data captured by the CIC, which shows data from each caliper finger as it moved up the wellbore (see Figure 4). This is valuable for double checking the notable wellbore sections to check if damage is localized or is prevalent throughout the wellbore.

From the information gathered from the survey, the resource management team will analyze, recommend, and decide if a safety workover is necessary for the well of concern.

Lastly, in order to track the corrosion, the wall thickness is plotted against time for specific depths and a rate of thinning can be computed. Using this data, it will be possible to predict when the walls thickness will approach BMAT.

However, due to the mechanical nature of the CIC tool, there may be issues with inconsistent tracking of thinning rate.

Additionally, it will not ensure complete coverage of the wellbore's circumference because of the spaces in between the caliper fingers. Because of this, CIC results are more suited for monitoring rather than forecasting.

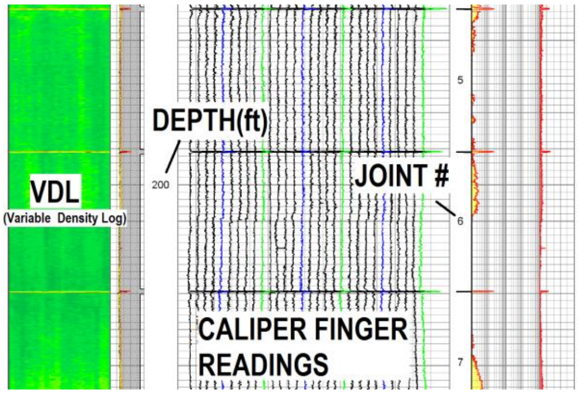

Figure 4: A diagram showing the separate readings of the caliper's fingers.

3. EVALUATION FOR WORKOVER

Before Bul-25 was included in the list of candidates for the 2017 work-over campaign, a detailed analysis was conducted. Included in the analysis is a lookback of its work-over history, and a review of both historical and recent CIC surveys.

Following the installation of a hangdown liner in 1987, CIC surveys were consistently ran into Bul-25 – a total of 10 runs from 1988 to 2005 showing that the hangdown liner was in reasonable condition but also showing signs of corrosion. When the CIC survey was run in 2011, a casing hole was found at 483 ft MD (147.2 m MD). See Figure 5, Figure 6 and Figure 7.

Because the depth is above 1000 ft MD (304.8 m MD), the finding is a cause for concern, despite the well operating at vacuum wellhead pressure as it could still build up pressure under shut-in conditions. Additionally, 16 joints of liner were found to be in BMAT condition due to corrosion, and this further reinforced that Bul-25 will need to undergo a workover in order to preserve its mechanical integrity. Its severely corroded hangdown liner is to be replaced with either a secondary tieback or a new hangdown casing to further extend the life of the 9 5/8 in (245 mm) casing. The use of a more exotic material that will be resistant to oxygen corrosion like titanium was also evaluated but was not economical and is also susceptible to H_2S embrittlement.

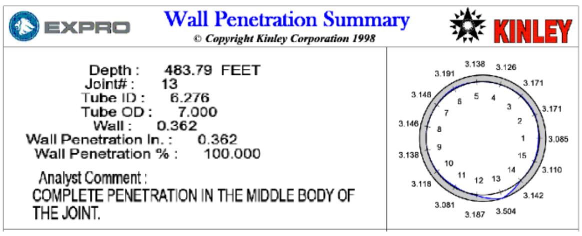

Figure 5: A cross section of the hangdown liner showing the casing hole found on Bul-25.

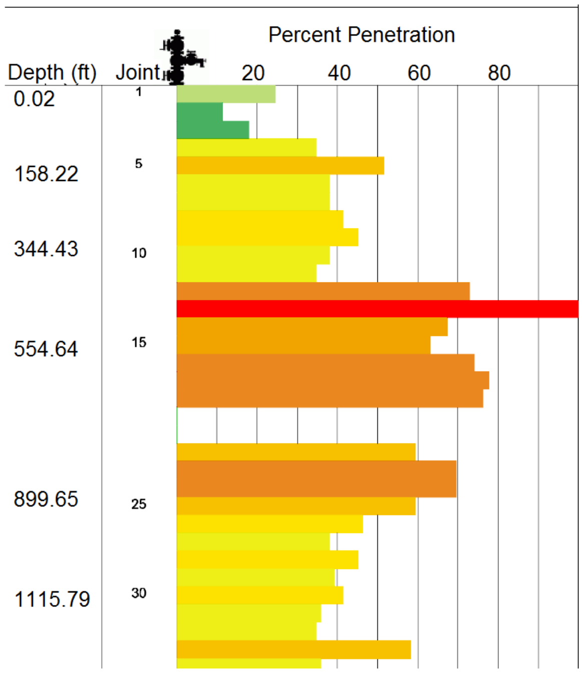

Figure 6. The penetration profile of Bul-25.

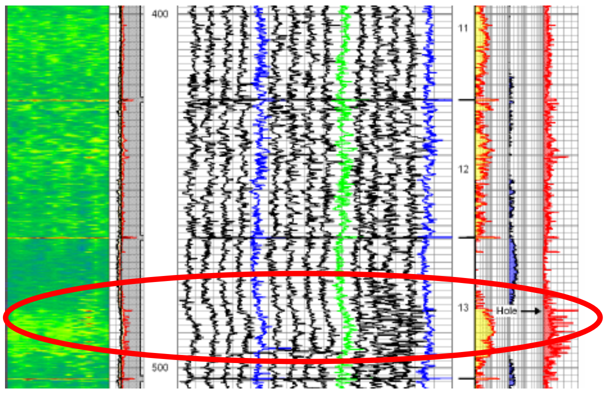

Figure 7. Raw CIC data showing the casing hole at 483 ft MD (147.2 m MD), with deformations surrounding the area.

Bul-25 has a high injection capacity, which is equivalent to 26% of CBCIS' total capacity. From this, a potential 137 kph (62 t/h) of steam losses may be incurred in the event of plugging and abandoning Bul-25 due to casing failure. This translates to 7.6 MWe in generation losses (Torres, et al., 2016).

4. EXECUTION

The workover of Bul-25 started in 2017 with the objective to restore wellbore integrity by replacing its hangdown liner with either a secondary tieback or a new hangdown casing. The decision would be made based on the condition of the retrieved liner, which should give the team an idea on the condition of the production casing.

A casing spear assembly combined with a casing cutter were used to extract the corroded hangdown liner because the initial plan to pull out the hang down liner in one piece did not materialize. The casing hole seen in the 2011 survey was first encountered at 446 ft MD (136 m MD) and had worsened into a parted casing. Because of this, the portion above this depth was pulled out without the need of a casing cutter. However, high over pull was experienced during the pull out of the remainder of the casing and, as stated in its 2011 CIC results, the hangdown liner was in poor condition (see Figure 8) and was extracted in small sections because of this. Also, following this finding, it was decided to run a secondary tieback, with the assumption that the production casing is also likely to be corroded.

Figure 8: A section of Bul-25's hangdown liner showing extensive corrosion.

It is also worth noting that findings in the 2011 CIC survey align with the actual condition of the hangdown liner. Seen in **Error! Reference source not found.** are streaks of corrosion and areas of pittings found along the liner, which is also seen in the caliper reading shown in **Error! Reference source not found.**.

A total of 2110 ft (643 m) of hangdown liner was successfully extracted from the wellbore. Aside from the depths stated above, it was also observed that general corrosion was present throughout the whole hangdown liner. The original casing behind the former hangdown was cleaned out before running and cementing the secondary tieback casing.

The secondary tieback casing included 51 joints of 7 in (178 mm) 29 pounds per foot (ppf) K-55 casing and 4 joints of 7 in (178 mm) 29 ppf L-80 which were ran and cemented to 2073 ft MD (641 m MD). These will serve as the permanent replacement for the hangdown liner (**Error! Reference source not found.**).

In order to confirm if the well has retained its injection capacity, an injection capacity test was performed using two rig pumps and a cementing unit. A total of 24 bpm (3.84 m^3/min) was injected into Bul-25 for 28 minutes, with the well on vacuum throughout the whole test. This indicated that the well has retained its original capacity after restoring its wellbore integrity.

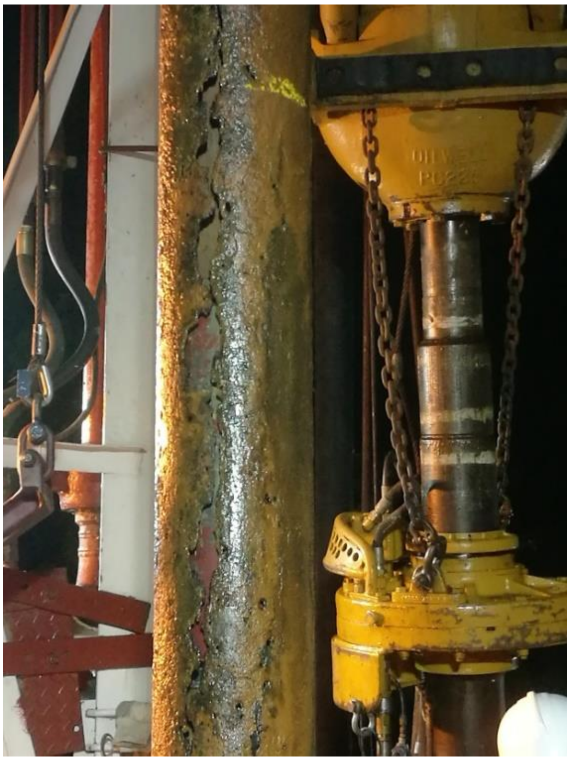

Figure 9: A section of liner approximately located at 800 ft MD (243.8 m MD) showing streaks of corrosion and pittings.

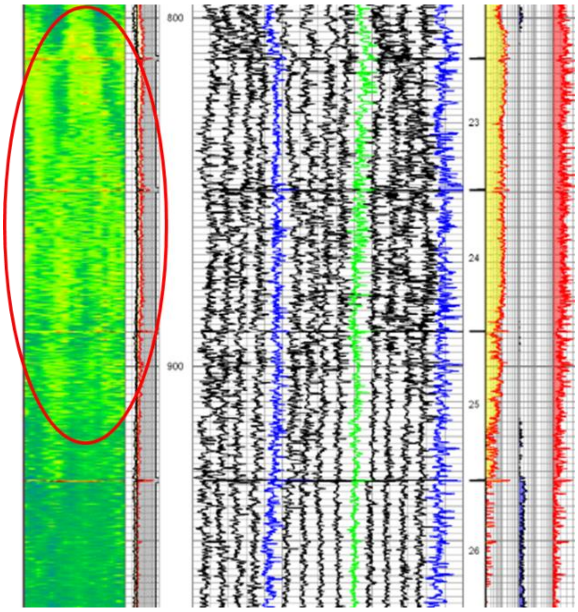

Figure 10: The readings at 800 to 900 ft MD (244 to 275 m MD) from the 2011 CIC survey.

Two weeks following its workover, Bul-25 was re-commissioned to CBCIS to serve as an injector and is still active until present day.

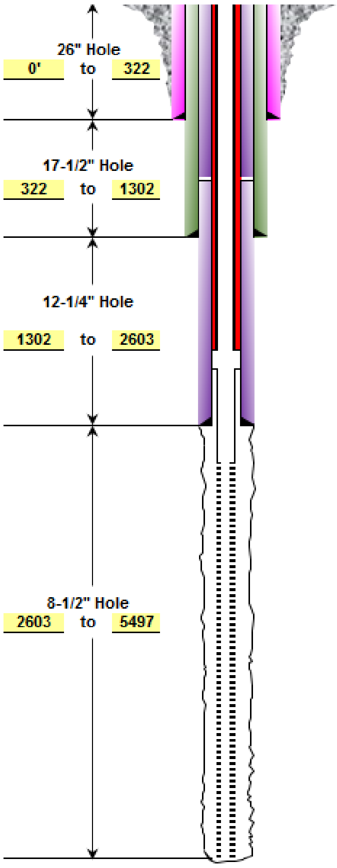

Figure 11: The wellbore schematic of Bul-25 (depths in ft) after the work-over (marked in red is the new secondary tieback).

5. CONCLUSION

Well integrity holds an important role in maintaining the safe and reliable operation of wells, producer or injector. Having a monitoring plan and an analytic process will greatly assist in tracking wells' wellbore condition. This has proven useful for a well such as Bul-25. Its hangdown liner was diagnosed correctly, and the corroded sections, which would have otherwise been unexpected if not for the CIC results, were dealt with efficiently. This workover has been an ideal case study for the analysis of wellbore integrity, and this process flow will be further used for other wells in the future.

6. RECOMMENDATIONS

Following the work-over of Bul-25, further efforts are being made in assessing the main causes of corrosion. Survey data from similar injection wells (cold brine/condensate accepting) show that the speed of corrosion is possibly due to a combination of factors, such as acidity of the condensate, high concentration of dissolved oxygen (DO) and also corrosion at the liquid level when injecting at vacuum wellhead pressures. The chemistry will be analyzed and mitigations may be applied in the form of pH modifications, corrosion inhibition dosing, and other non-invasive methods. It is advisable to inject at positive wellhead pressure to ensure that there is no free oxygen present in the casing.

Lastly, the methods for monitoring wellbore integrity are still being further refined to be more specific to well type. Because of the differences in fluid type, producers and injectors may be surveyed at different frequencies, and the analysis may differ as well.

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