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Fluid Management System – Acid Well Neutralization Experience for the Biliran Geothermal Field, Province of Biliran, Philippines

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ABSTRACT

The Biliran Island hosts one of the promising underdeveloped geothermal resources in the Philippines. The Philippine National Oil Company – Energy Development Corporation (PNOC-EDC), initially explored the resource in 1978 to 1982 and drilled three (3) delineation wells. This was later abandoned due to extreme acidity of one (1) of the wells drilled. In the year 2008, another developer attempted to harness the neutral zone of the resource, unfortunately, most of the additional five (5) wells drilled were also acidic. To make use of said wells, scientists and engineers worked together to create the Fluid Management System (FMS). The well used for the experimentation of the FMS is BN-06D. This well initially discharged neutral fluids but when simultaneously discharged with BN-07D, believed to be sharing feed zones with BN-06D, it discharged geothermal waters with acidity. FMS used diluted caustic soda (NaOH) to neutralize the acidity of the well. The system can be divided into three components, the Holding Tanks, Mixing Tanks, and Injection Setup. Diluted caustic soda was injected inside the well thru 2/8" capillary tube placed just above the projected flash point. After three (3) months of discharge testing, the test obtained power plant-acceptable pH levels throughout the test, despite the cyclic behavior of the well. This was further supported by significant decrease of Fe and Mg concentrations, no considerable thinning of above ground piping, and minimal thickness reduction of the production casing (multi-finger caliper survey). In conclusion, the Fluid Management System (FMS) is successful and BN-06 may now be utilized for 4.2 MWe geothermal power.

1. INTRODUCTION

The Philippines being a relatively mature geothermal country, development was put into stand-still over the last decade. Future of geothermal development in the country lies to untapped unconventional resources such as low-enthalpy resources and acidic fluids. Biliran Island hosts one of the promising underdeveloped geothermal resources in the Philippines – Biliran Geothermal Project with power potential range of 93 to 371 MW (FEDCO, 2009). Like any other volcanic hosted resource, Biliran Geothermal Project is characterized by the presence of an acidic corridor. These acidic fluids hindered the Project's development, affecting its viability and sustainability.

The Biliran Geothermal Project is situated within the lone island province of Biliran north-northwest of the geothermal-rich island of Leyte. Biliran Island lies in proximity to the Philippine Fault Zone, which has been characterized by active volcanism and tectonism since the Miocene.

Many developers attempted to harness the geothermal potential of Biliran Island. PNOC-EDC conducted its geoscientific studies in 1978, which led them to drill three (3) standard vertical wells (BN1 to 3). One of the three wells discharged high enthalpy and acidic fluids. This damaged the well head and prompted the PNOC-EDC management to abandon the project. In the year 2008, a venture by Icelandic and Philippine companies formed Biliran Geothermal, Inc. (BGI). BGI conducted additional geoscientific studies and drilled five (5) additional production wells (BN4 to 8) with the intent to harness the neutral zone of the resource. Unfortunately, all of the newly drilled wells were found out to be acidic. Emerging Power Incorporated (EPI) – a company with a vision to develop new frontiers of renewable energy, bought in to the almost helpless BGI. They engaged engineers and scientist to develop a system that can harness the potential of such acidic resources, hence, Fluid Management System (FMS) was formed.

2. RESOURCE MODEL – SOURCE OF ACIDITY

The resource of the Biliran Geothermal Project is volcanic-hosted similar to other geothermal resources in the Philippines. Such volcanic-hosted geothermal resources, acidic corridors are inherent especially to areas with young volcanism. The Biliran resource's postulated upflow is situated below BN-03, the acidic well drilled by PNOC-EDC, with temperatures reaching 332ºC and impressive thermal manifestation in proximity. The acidic upflow is postulated to be caused by a magmatic heat source beneath Vulcan Dako, which releases acid forming gases such as HCl and SO_2. These gases would be incorporated to the geothermal reservoir rendering acidic fluids.

On the outflow of the resource, cooler but neutral fluids are to be expected. The acidic fluids react to the host rocks consuming its H^+ ions neutralizing the fluids as you go further away from the upflow. This was proven in wells BN-01 and BN-02, both exhibited neutral fluids with lower temperatures compared to BN-03.

3. FLUID MANAGEMENT SYSTEM (FMS)

Fluid Management System is a method devised by BGI to utilize drilled acidic wells for the initial development and capital recovery of the project. BGI patterned the FMS to the method applied in the Miravalles Geothermal Field, Costa Rica where caustic soda is injected within the well bore to protect the casing and the above ground facilities. FMS utilizes one of the basic lessons in chemistry,

Figure 1: Location Map of the Biliran Island derived from Google Earth. Onset map located on the bottom left corner.

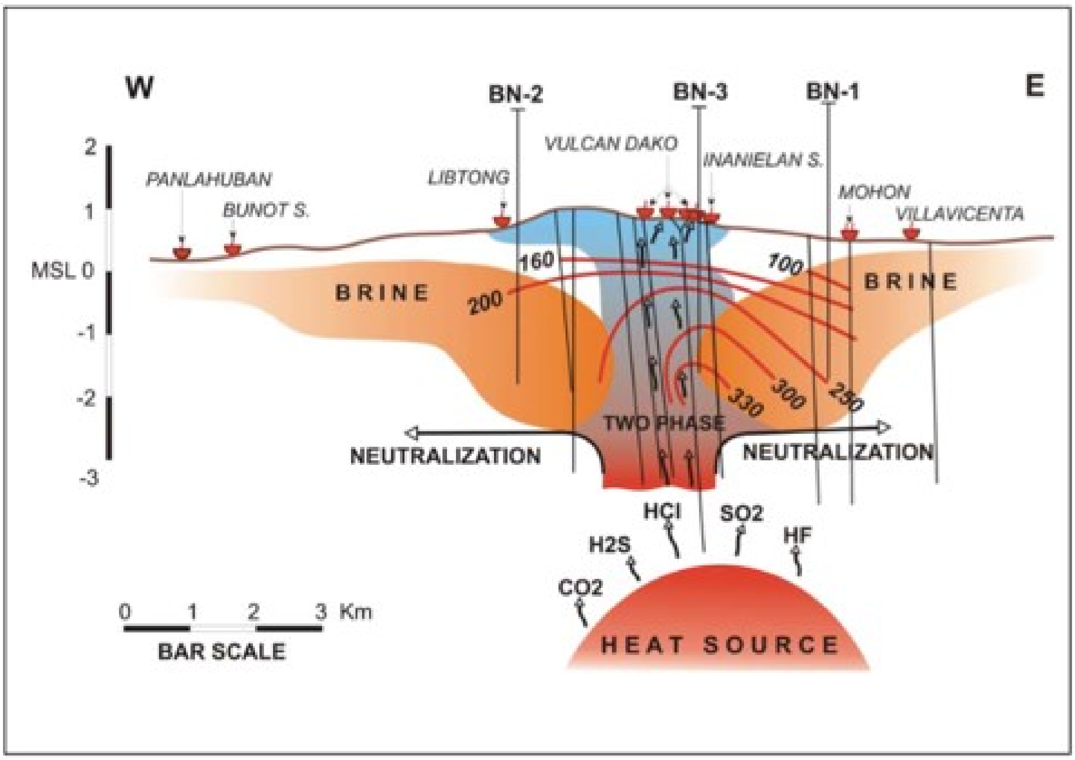

Figure 2: Scaled conceptual model of the geothermal resource in Biliran followed from Candelaria and Baltasar, 1993.

acid neutralization. Below are the two (2) common acid neutralization process that occurred in the well bore during the FMS:

$$H_2SO_{4(aq)} + 2NaOH = Na_2SO_4 + 2H_2O$$

$$HCl_{(aq)} + NaOH = NaCl + H_2O$$

In this specific test, BGI employed the FMS for well BN-06D, which showed relatively mild acidity, compared to the other wells drilled, during the initial discharge tests conducted last 2014. This well initially discharged neutral fluids but when simultaneously discharged with BN-07D (acidic), BN-06D gradually changed its discharged fluids to acidic with similar chemistry to BN-07D. This was believed to happen because the two (2) wells are sharing feed zones.

The test used diluted caustic soda (NaOH) to neutralize the acidic discharge of the well. Then this will be injected in to the well bore using a high-pressure chemical pump through a 2/8" OD stainless steel coiled tubing and out to a stainless injector head. The injector is placed just right above the flash point, where fluid from the well starts to vaporize. This enhances the effect of the neutralization because there are less liquid to interact with NaOH as part of the fluid turned to steam.

3.1 Components

FMS is composed of several components with specific functions that is vital to the operations and effectiveness of the test. The components are namely the (1) Storage Tanks, (2) Mixing Tanks, (3) Transfer and Holding Pumps, (4) Injection Pumps and (5) CTU and the Injector Head. This section provides additional information on the said components.a

3.1.1 Storage Tanks

Two (2) type of tanks were used to store industrial grade (48-50% NaOH) caustic soda and fresh water. Both tanks are 10,000L Polyethylene Storage Tanks with UV Stabilizers. The tank for the caustic soda storage is white while blue was used for the water to minimize algal formation. These tanks are connected to the mixing tanks by PVC pipes, fittings and valves transferring both liquids by gravity.

Figure 3: Storage tanks used for caustic soda (white) and water (blue). Both are made up of polyethylene material with UV stabilizers.

3.1.2 Mixing Tanks

The use of the mixing tanks is to provide homogenous solutions of desired concentrations of NaOH. These mixing tanks are fabricated using 1,000L water storage tanks installed with stainless steel paddles powered by 1hp rotating motors. The setup is duplicated to provide flexibility to the operations, such as change in NaOH concentrations to be injected, etc. In BGI's experience, it takes one (1) to two (2) hours of mixing to attain a homogenous solution.

3.1.3 Transfer Pumps and Holding Tanks

Pumps used as transfer pumps are Pulsafeeder metering pump model No. GLM2D and GLM1C. Both pumps are low-pressure (up to 10 barg), chemical resistant, metering pumps (up to 80 li/hr), previously used for the in-line mixing of caustic soda and water. In an earlier experimentation, dilution of caustic soda was done by pumping pre-determined volume of caustic soda and water simultaneously into a 1.5 meter in-line static mixer. However, it was found that the current length of the static mixer is not enough to create a homogenous solution. For the second attempt, the mixing tanks from the previous section was fabricated and the old mixing pumps were used as transfer pumps to move the solution to a fabricated 1,000L stainless steel holding tank equipped with level sensors that automatically shutdowns the transfer pump upon reaching the set capacity.

3.1.4 Injection Pump

From the holding tank, the solution will be pumped out to the well bore using Pulsafeeder 7660-S-E, a high pressure (up to 120 barg) chemical resistant pump that can pump up to a rate of 240 li/hr. The injection pump serves as the heart of the FMS. The pump is directly coupled to 1.5-hp, rpm, 230-V, single-phase, 60 Hz, Totally Enclosed, Fan-Cooled (TEFC) motor. Normal operating pressure for the pump is 1,200 psig or 82 barg, pump rate is adjusted adjusting the stroke length. Two (2) pumps are installed, for the other pump will serve as a 100% back-up in cases of bog downs of the initially used pump.

Figure 4: Fabricated mixing tanks used to attain a homogenous solution of desired concentrations of NaOH.

Figure 5: Stainless steel holding tank (left) and Pulsafeeder GLM series transfer pumps (right)

3.1.5 Capillary Tubing Unit and Injector Head

If the injector pump is the heart of the FMS, the capillary tubing unit (CTU) is the vein system or vessel that carries the diluted caustic soda to neutralize the well discharge. The CTU should be able to handle the corrosiveness of the diluted caustic soda and acidic geothermal fluid, pressure from both the pumps and the well bore, and tensile stress from the winch and injector head. A stainless coiled tubing with 2/8" opening diameter was chosen. Lastly, the last stop of the solution before it neutralizes the acidic fluids of the well bore is the injector head. Aside from the previously stated, it also serves as an anchor to the CTU to prevent it from being washed out by the discharge. The injector head is composed of several stainless and heavy alloy.

3.2 Test Procedure

Figure 8 summarizes the test procedure for the BN-06D FMS testing. Upon discharge, the pH of the fluids is measured every 30 minutes, intervals may be longer depending the stability of the succeeding measurements. If the pH is above 3.5, the Surface FMS may commence. However, if pH is less than 3.5, the Downhole FMS should be implemented to alleviate the pH and prevent further damage to the casing and the above ground facilities. Dosing will commence with the goal to attain power plant acceptable pH range of 4.5 to 5.5. There are two (2) ways to adjust the dosing. First is to change the pump rate of the injection pumps by adjusting the stroke length and the second one is to change the concentration of NaOH. Less adjustment will be needed for the previous and its effects may be observed almost instantaneously. On the other hand, for the second one, the contents of the holding tank should be emptied plus the solution with the previous concentration must be displaced out of the 2,000 m CTU before the effects of the adjustment may be observed. If necessary, both dosing adjustment methods may be integrated. Finally, if the bore output of the well (Cl concentration, bore output measurements) and the pH is stable the discharge and test may be terminated. The test started last 15 November 2018 and ended upon the criteria was met last 30 December 2019.

Figure 6: Pulsafeeder 7660-S-E used as injector pumps for the FMS. Two (2) units are installed to serve as a 100% back-up.

Figure 7 (Left Picture) Winch with the CTU set-up covered in tarpaulin to protect from inherent corrosiveness of geothermal fluids (left) and the well head set-up installed with the recovery spool for the injector head (right). (Right Picture) Injector head after the FMS test.

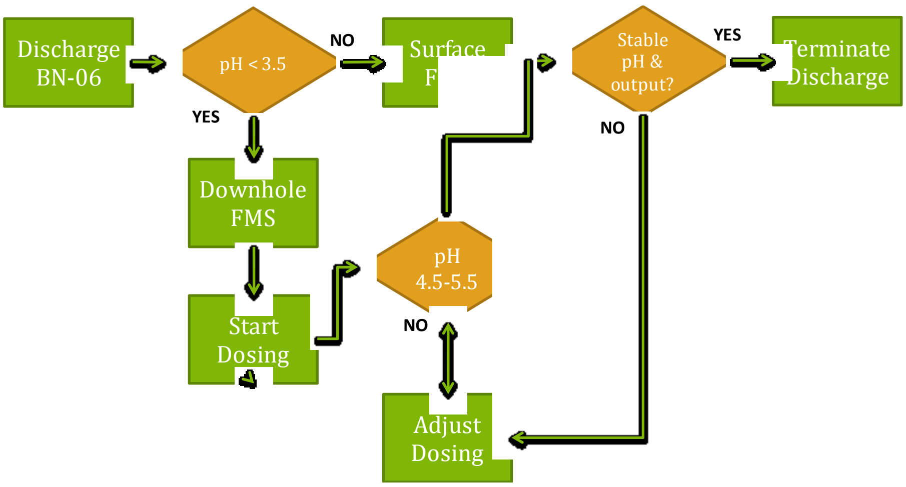

Figure 8 Flow chart of the procedure of the FMS Test

4. RESULTS

4.1 pH Trend

On November 15, 2016, the neutralization test was started with the modified mixing system in place. The injector head of the capillary tubing unit (CTU) was set at 700m below CHF, which was the projected initial flash point. The fluid discharge started at a pH of 2.6 units and was initially treated with 22.0% NaOH concentration at 100 li/hr solution injection rate. Continuous adjustments were made on the NaOH concentration and solution injection rate with the objective of keeping the treated pH between 4.5 to 5.5 pH units. This was attained at an injection rate of 58 li/hr at 15% NaOH concentration on November 17.

As shown in Figure 9, most of the data lie within the 4.5 – 5.5 pH band with few outliers which is believed to be largely caused by the cyclic behavior of the well, meaning shifting production from two or more zones. Stable iron concentration trend (See Figure 10) shows that minimal corrosion of the production casing is taking place, indicating that the treatment process is effective.

The drop in the injection flow rate coincided with the well having drawn down and becoming more two phase, i.e., that is, the liquid phase has decreased thereby having less liquid phase to treat.

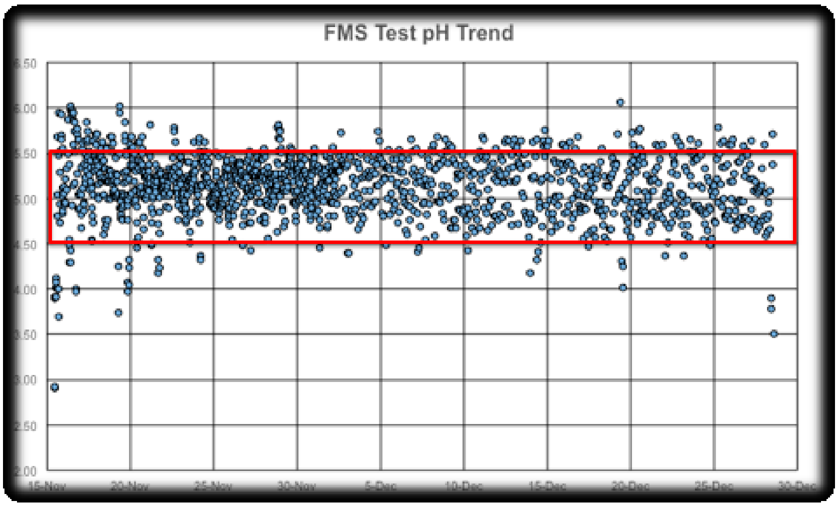

Figure 9: pH trend recorded during the FMS test period (15 November to 30 December)

4.2 Cyclic Bore Output Measurements

BN-06 exhibited cyclic behavior (see Figure 11) that is typical for wells with two (2) or more feedzones with at least one (1) zone of relatively poor permeability. Feedzones of lower permeability cannot sustain continuous flow, hence contributes intermittently to discharge. Initially, BN-06 discharge is characterized by decreasing well-head pressure (WHP) and mass flow (MF), and increasing enthalpy but recent trends show stable WHP and approaching stability for MF.

Calculated output for the well BN-06 upon stabilization of the bore output is at 4.2 MWe gross. Calculations were based from the assumptions that a binary-type of power plant will be used.

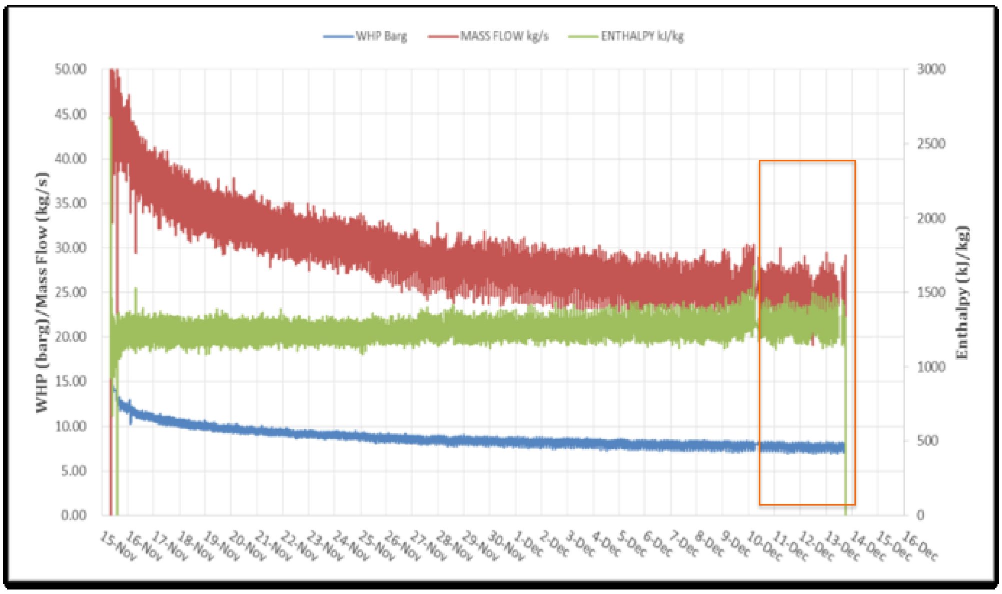

Figure 10: Bore output measurements for BN-06D for the duration of the FMS test (WHP, MF, Enthalpy)

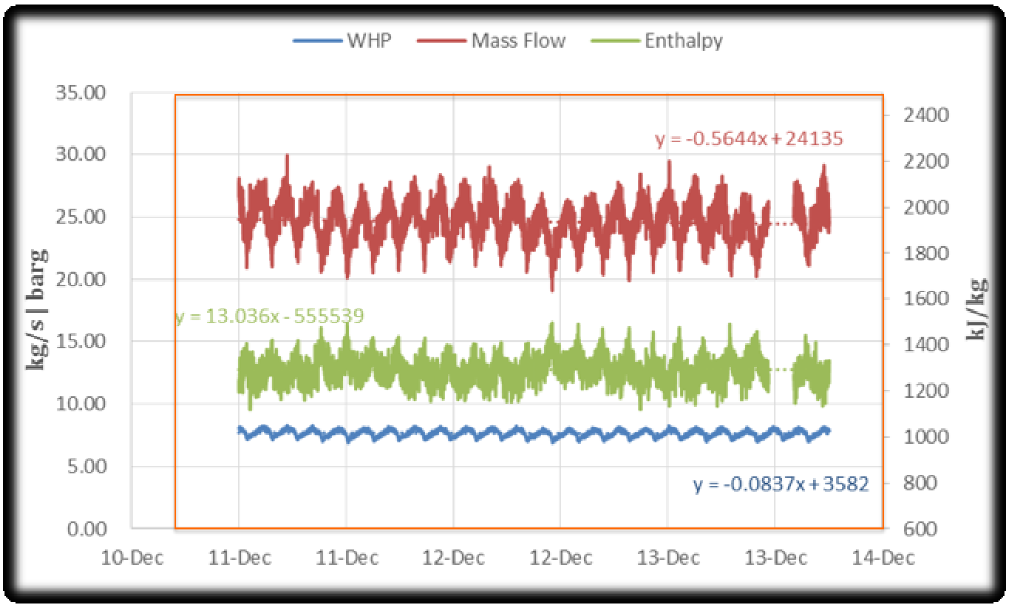

Figure 11: Zoomed-in of Figure 10, focusing on the period 11 December to 13 December 2016. Figure shoes cyclic behaviout of the well with frequency of 3 cycles per hour.

4.3 Iron and Chloride Concentrations

During the FMS test, most of the common geochemical parameters were recorded. However, for the purpose of this writing, the authors decided to focus on Iron (Fe) and Chloride (Cl) concentrations. Cl is monitored as it indicates the stability of the discharge. The Cl concentration of BN-06 was stable at around 6,000ppm, as depicted from the figure below. This strongly indicates that the discharge is stable starting from the first week of December throughout the end of the test. On the other hand, Fe is not inherent in geothermal waters, abnormal concentrations may indicate metal loss from the casings and well-head assembly. Fe concentrations of BN-06 significantly dropped from 110 ppm to 20 ppm. Please note that the treatment is set at 700m from the casing head flange (CHF) leaving the casing below susceptible from corrosion.

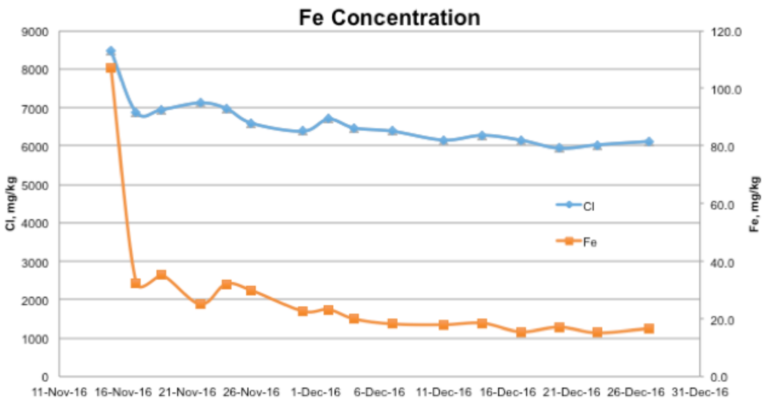

Figure 12 Iron and Chloride concentrations of BN-06D discharge for the period of the FMS test

4.4 Multi-finger Caliper Survey

Scientific Drilling, Inc. (SDI) was commissioned to conduct a post-FMS Multi-Finger Caliper Survey Run for BN-06D. Results (Figure 13) show that the production casing of the well did not sustain significant metal loss and deposition. The caliper survey run is specific for a standard type of hole with 9" OD. Note that the casing was never replaced and possibly the metal loss was due to suspended solids during the initial discharges.

Depth	Summary
CHF – 535m MD	Average Metal Loss (0 to 10%)
535m – 710m MD	Average Deposition (-4 to -32%)
710m – 855m MD	Average Metal Loss (1 to 8%)
855m – 938m MD	Average Deposition (-3 to -16%)
938m – 956m MD	Average Metal Loss (2 to 12%)

Figure 13 Summary of Multi-Caliper Survey conducted after the FMS Test.

Figure 14: Dark discharge out of the weir box of BN-06D near the end of the FMS test.

Another observation was noted for BN-07D, a well within the same pad as BN-06D. BN-07D was found to have responded actively during the flow test of BN-06D as indicated by its rising wellhead pressure and hot wellhead. To minimize steam accompanying the discharge, a throttling valve was installed. With ¼ opening adjustment of the throttling needle valve, drastic increase in WHP was observed. Downstream temperature (after the valve) went as low as 30°C, this is most probably due to small amount of steam and gas combination, not having enough heat to increase the temperature of the pipe. Upstream temperature also decreased to 83°C, indicating that steam might have been suppressed after the throttling. BN-7 was shut right after BN-6 discharge was terminated, WHP build up to 68 barg with hot well head. With this communication, and BN7 having a hot down hole temperature (+300°C) at the bottom, this well can be used an injection well to provide recharge to BN6 but its injection rate should be properly controlled to arrest any detrimental effect to BN6.

Figure 15: Well Head Pressure (WHP) of BN7 seen rising as it reacts to BN6 discharge

5. CONCLUSION

The Fluid Management System carried out by BGI was deemed effective and successful for the following reasons:

- ✓ In spite of the cyclic behavior of the well, the pH of the well was maintained to a stable range of 4.5 to 5.5 with average NaOH concentration of 15% with about 58 li/hr pump rate;
- ✓ The Iron (Fe) concentration which started at an initial value of 155 ppm before treatment stabilized at ~20 ppm immediately after treatment;

- ✓ Multi-Finger Caliper survey showed minimum metal loss to average deposition throughout the 44-day test period. Note that the casing was never replaced and possibly the metal loss was due to suspended solids during the initial discharges.

Nevertheless, as seen in this writing, harnessing acidic geothermal resources entails new sets of risk that may be detrimental to the project and nearby communities. BGI needs to ensure that the pH levels should be on the sweet spot (4.5 to 5.5) in order to prevent corrosion and unwanted precipitations inside the well bore and the above ground facilities. Another issue to be vigilant about is the sudden rising of the WHP of the BN-07D. Uncontrolled wells may lead to unwanted discharges or even blow outs.

BGI plans to put up a modular binary power plant using BN-06D as the producer to supply to the Biliran's distribution utility (BILECO). 4.2 MWe is more than enough for the whole island's power requirements. Everyone in the geothermal industry is excited for the development of this resource but the local cooperative is not supportive of the project and they claim that their demand is committed to a local coal-fired power generator. Due to this BGI is unable to attain its financial close, stalling its development.

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