Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Reservoir Changes as Manifested in the Geochemical Signature of Production Fluids: Maibarara Geothermal Field , Philippines

Lea Carmelia D. Fernandez, and Maria Victoria M. Olivar

Maibarara Geothermal Inc., 7F JMT Building, ADB Ave. Ortigas Center, Pasig City, Metro Manila, Philippines

ldfernandez@maibarara.com.ph

Keywords: Maibarara, geochemical response, production, reinjection

ABSTRACT

The 32 MW Maibarara Geothermal Power Facility (MGPF) is located on the northwest flank of the inactive stratovolcano, Mt. Makiling, about 70 km south of Manila, Philippines. The facility consists of 1x20 MW and 1x12 MW geothermal steam turbines. The 20 MW Maibarara-1 Geothermal Power Plant (M1GPP) has been in operation since February 2014 while the 12 MW Maibarara-2 Geothermal Power Plant (M2GPP) was commissioned in April 2018. The production wells, power facility and reinjection wells are located in a compact area of around 7.5 hectares.

Three wells provide steam to the two power plants while the effluents are injected back into the reservoir via two (2) reinjection wells. Production and reinjection in Maibarara is concentrated in a 2.5 km^2 resource area and with continuous mass extraction, changes occur in the reservoir. These changes are directly manifested in the chemistry of the production wells and in turn provide an insight on how to manage the reservoir.

This paper discusses the field's geochemical response to production since its first commercial operation in 2014 and the subsequent capacity expansion in 2018.

1. INTRODUCTION

The 20 MW Maibarara Geothermal Power Plant lies on the northwest flank of the inactive stratovolcano, Mt. Makiling. The field is located within the tectonically active region called Macolod Corridor in the island of Luzon where two volcano-tectonic depressions, several inactive domes, a maar field, and thermal areas are located. The field was previously explored by UNOCAL and Philippine Geothermal Inc. (PGI) and five of the twelve wells drilled between late 1970s to mid-1980s were found commercial. However, development was shelved until the rights to the area were relinquished back to the Philippine government in mid-2000s (Delfin, et.al, 2009). In 2009, the area was offered for bidding by the Department of Energy (DOE) and the service contract was awarded to PetroEnergy Resources Corporation (PERC) in February 2010 and transferred to the Joint Venture Company, Maibarara Geothermal Inc. (MGI) in July 2010.

The Maibarara Geothermal Power Facility has a combined installed capacity of 32 MWe from its two geothermal power plants. Wells PW-1 and PW-2 supply the steam required by the 20 MW Maibarara-1 Geothermal Power Plant (M1GPP). The two wells produce more than 20 MW and the excess steam is combined with steam from a third production well, PW-3, to operate the 12 MW Maibarara-2 Geothermal Power Plant (M2GPP). M1GPP started commercial operations in February 2014 and the second unit, M2GPP, was commissioned four years later in April 2018.

Changes in concentration of conservative species such as chloride provide useful information about the prevailing processes that take place in the subsurface (Brown, 1988). Other parameters considered are enthalpy, geothermometry and gas trends. Chemical trends are correlated with physical parameters measured at the surface for interpretation. This paper discusses the field's response to production based on geochemical data and physical parameters from start of production until end of 2018.

2. GEOCHEMICAL RESPONSE TO PRODUCTION

All three production wells in MGPF produce neutral, high temperature two-phase fluids with average enthalpy of 1900 to 2100 kJ/kg and chloride content between 5000 to 8000 ppm. Field reinjection is done through a cold reinjection system where separated fluids are diverted to thermal ponds for cooling. The cooler fluids along with the power plant condensates are pumped to two reinjection wells, drilled at the edge of the field.

2.1 Reservoir Boiling

The reservoir pressure drops in the beginning of exploitation as the reservoir responds to continuous and large-scale fluid extraction. Fluids boil in response to the drop in pressure. In geochemistry, boiling is characterized by increasing chloride concentration, gas content, and discharge enthalpy. At the surface, manifestations often include increasing steamflow at first but if not properly managed, may translate to decrease in the well's total mass flow later on.

Both PW-1 and PW-2 show evidence of boiling in 2014 as the field started commercial operations (Figure 1). Compared to the PW-1's baseline chloride concentration of 4760 ppm, the average reservoir chloride increased to 5500 ppm during the first five months after commercial operations in February 2014. CO2 at the wellhead also increased from 375 to 550 mmol/100-mol H_2O. No other significant episodes of boiling has been observed in PW-1 since then.

In PW-2, trends of boiling were observed in the early production stage and again in 2017 after the well recovered from reinjection returns. Similar to PW-1, the chloride in well PW-2 increased from its average baseline concentration of 7480 ppm to a high of 8500 ppm within a period of five months after the plant's commercial operations; average CO2 also increased from 510 to 850 mmol/100-mol H_2O within the same time period. Additional boiling trend is observed from May 2017 where chloride slightly increased from about 6000 ppm to 7500 ppm as the well recovered from RI returns. There was a corresponding increase in gas content from 620 to about 800 mmol/100mol-H_2O, further indicating that boiling is the dominant process in the reservoir.

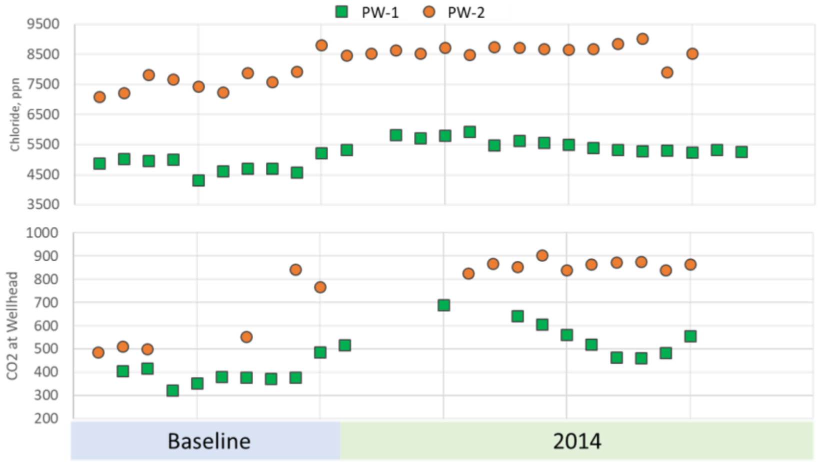

Figure 1. Boiling trends manifested by wells PW-1 and PW-2 in 2014 after start of M1GPP commercial operations.

In well PW-3, fluids are saturated with calcite and boiling results to the formation and deposition of calcite scales. Figure 2 shows the trends of water and gas chemistry of the well from its discharge testing up to commissioning in 2018. Scaling was first observed during the well's flow-testing in late 2016 when the mass flow abruptly declined and gas content increased sharply from 450 to 950 mmol/100-mol H_2O. The well was worked-over and acidized in 2017 and cuttings recovered were identified as silica, from the well's usage as RI, mixed with calcite. The rate of deposition, however, was not established since the well was shut to make way for steamfield construction in preparation for capacity expansion.

Wellbore simulations indicate that calcite scaling would be restricted to the formation if the well's enthalpy is above 1400 kJ/kg (MGI Internal report, 2017). Fluid chemistry trends indicate boiling at the beginning of commissioning in March 2018 with chloride at ~7000 ppm and CO2 above 1000 mmol/100mol-H_2O; however, the well was highly two-phase with enthalpy close to 1500 kJ/kg hence preventing the formation of calcite scales inside the wellbore. The well maintained stable MW output and has not required any well intervention since commissioning up to end 2018.

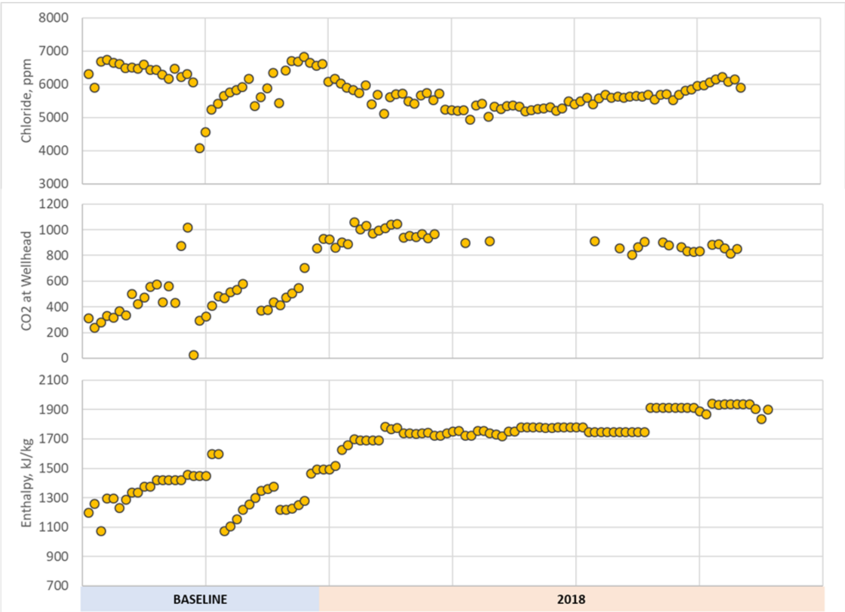

Figure 2. Chemistry trends of well PW-3 from flow-testing after conversion from RI well to commissioning and production in 2018.

2.2 Reinjection Returns

Reinjection is one of the primary requirements in sustainable geothermal operations. Environmental policies in the Philippines prohibit geothermal fields from discharging residual brine to rivers and nearby surface water systems. Separated fluids are instead returned back to the subsurface through reinjection wells drilled on the edge or outside of the main production zone. However, while reinjection provides pressure support and ensures resource sustainability, premature return of insufficiently-heated fluids have detrimental effects to the resource.

Starting January 2015, well PW-2 manifested increasing chloride, decreasing gas content, and decreasing reservoir temperature. Over a one year period, the average chloride increased from 8200 to 10400 ppm, gas content decreased from 850 to 515 mmol/100mol-H_2O, and Na-K geothermometry decreased from about 340°C to 315°C. The trends indicated entry of reinjection fluids from well RI-3 and a reservoir tracer test conducted in April 2016 confirmed the connection between the two wells. PW-2's water flow and steam flow increased during this period and plant generation was not affected.

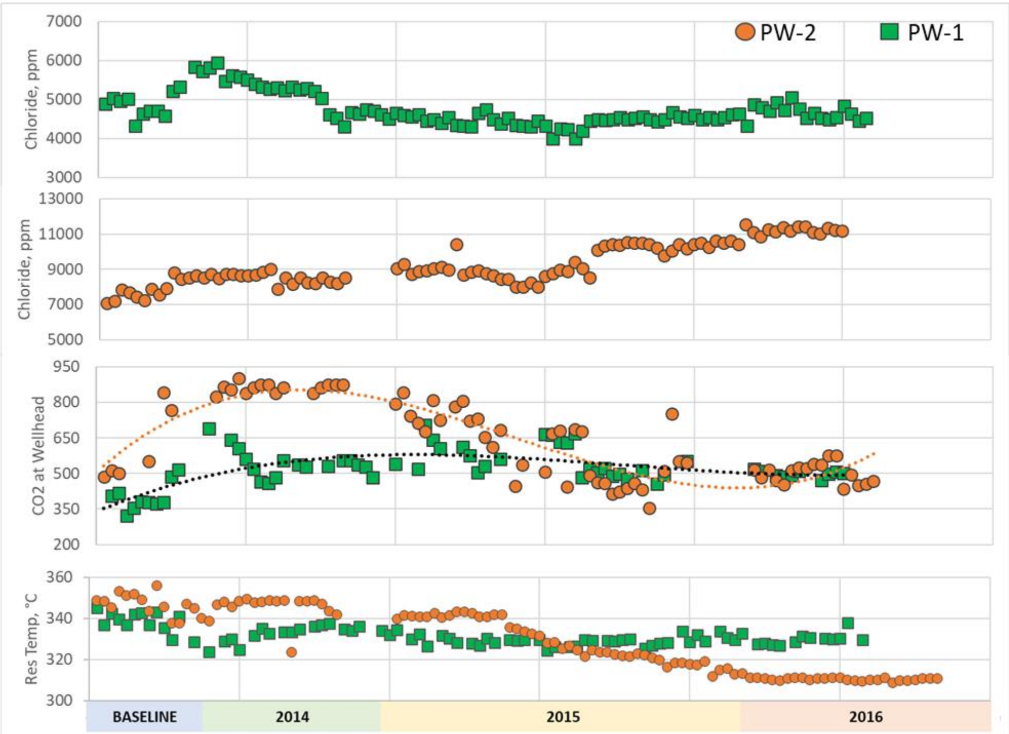

Figure 3. Manifestation of RI returns in production wells PW-1 and PW-2 were observed as early as 2015 and peaked in 2016.

In PW-1, reinjection returns were observed between September 2015 and April 2016. The changes in chemistry were gradual compared to PW-2 but chloride increased from about 4500 to 5000 ppm, while gas content showed a slight decrease from 520 to 500 mmol/100mol-H_2O. Reservoir temperature was not significantly affected.

In the case of PW-3, the well was previously utilized as reinjection well before it was converted to production well. Hence, fluids discharged by the well during periods of flow-testing in 2015, 2016, and 2017 have very high chloride and low gas content. Chloride values only stabilized beginning March 2018, about three years after conversion. Reinjection returns are not observed to date.

2.3 Dilution

The shift in reinjection and discontinued use of RI-3 as reinjection well proved to be efficient in mitigating reinjection returns and reservoir cooling especially in well PW-2. Chloride values significantly decreased while gas content and fluid temperature recovered. By late 2016, however, the chloride concentration of both PW-1 and PW-2 is lower than its baseline concentration indicating another reservoir process taking place.

Figure 4 below shows a plot of chloride and enthalpy at the reservoir condition. Chloride decreases but enthalpy and cation geothermometry remain stable thus eliminating influx of cold peripheral waters as cause of dilution. Another model is the presence of steam or steam condensate diluting the reservoir fluids. Steam forms as fluids in the rock matrix boil; the steam migrates to fractures and eventually to the wellbore which results to lower chloride without any detrimental effect to the reservoir enthalpy (MGI Internal report, 2018).

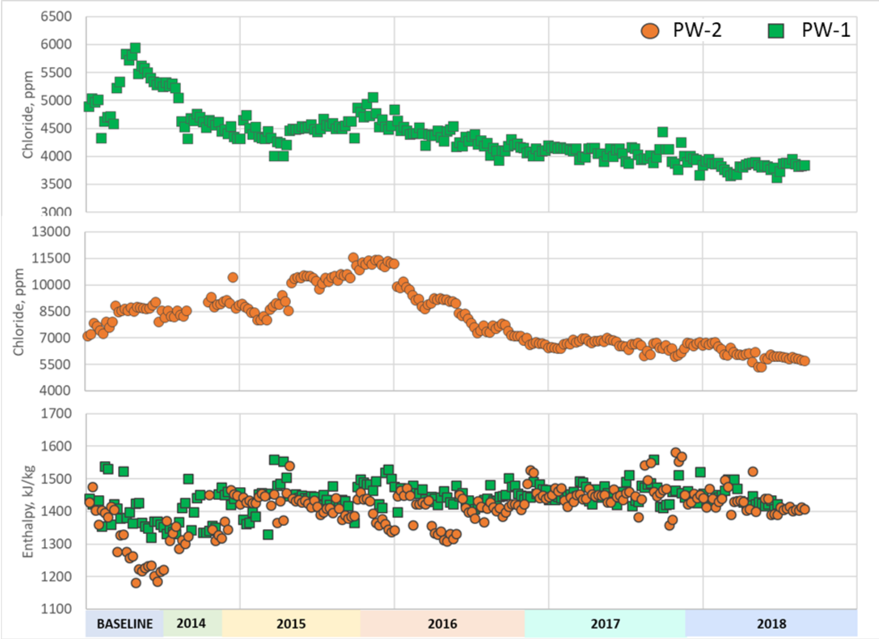

Figure 4. Lower chloride trends observed in wells PW-1 and PW-2 after the wells recovered from reinjection returns.

3. CONCLUSIONS

The Maibarara geothermal resource shows dynamic response to production. Effects of boiling, reinjection returns, and dilution are manifested in geochemistry trends as well as parameters monitored at the surface. While boiling and steam dilution are subsurface processes that are beyond the operator's control, re-entry of cold reinjection fluids was effectively mitigated by shifting reinjection to another sector of the field.

To date, the three production wells are showing stable chemistry and MW output with minimal decline rates thus making the 32MW production sustainable.

ACKNOWLEDGEMENT

The authors would like to thank the management of Maibarara Geothermal Inc. for permission to publish this paper and providing support for this work.

REFERENCES

Aydin, H., Akin, S., Tezel, S.: Practical Experiences about Reservoir Monitoring in Alasehir Geothermal Field, Proceedings, 43rd Workshop in Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2018)

Brown, K., Henley, R., Glover, R., Mroczek, E., Plum, H.: Dilution and Boiling in the Wairakei Field due to Exploitation 1959-1982, Proceedings, 10th New Zealand Geothermal Workshop, (1988)

Dean, A., Bixley, P., Lim, Y., Mroczek, E.: Effects of Reinjection at Wairakei Geothermal Field, Proceedings, 36th New Zealand Geothermal Workshop, Auckland, New Zealand (2014)

Delfin, F., Esberto, M., Manzano, E., Fernandez, L.: The Maibarara Geothermal Field: Geologic Setting, Exploration History, and Resource Assessment, Renewable Energy Service Contract Application to the Department of Energy – Maibarara Geothermal Project, Taguig, Philippines (2009)

Internal Reports and Memorandum, Maibarara Geothermal Inc. unpublished (2014-2018)

Olivar, M., Fernandez, L., Cruz, D., Isip, R., et.al.: Resource Characterization, Reserves Estimation, and Development Scheme of Maibarara Geothermal Field, Philippines, Proceedings 9th Asian Geothermal Symposium, (2011)