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Evolution of the Reinjection System in a Compact Operating Geothermal Field: the Maibarara Experience

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ABSTRACT

Reinjection of separated brine is a major concern of the Maibarara Geothermal Field. The development plan for the Maibarara Field is compact where the production wells, steamfield, power plant and reinjection wells is situated in a 7-hectare area. Maibarara System was originally designed for an infield hot reinjection where separated brine will be injected into a very hot reservoir (>300°C) at an injection temperature of 162°C.

Reinjecting hot brine into a hot reservoir in Maibarara, however, proved to be difficult, thus, a cold reinjection system was implemented. Through time, the cold reinjection system evolved due to the response to reservoir exploitation, steam production strategy and the capacity of the injection wells at different injection temperatures.

This paper will describe the reinjection challenges that Maibarara encountered and evolution of the reinjection systems in managing brine reinjection.

1. INTRODUCTION

The Maibarara Geothermal Field is located 70 kms southeast of the Philippines capital city of Manila it is one of the two productive geothermal reservoirs associated with Mt. Makiling, an inactive andesitic stratovolcano with a summit elevation of 1090 m. The Maibarara field is situated at the NW flanks of Mt. Makiling while the other field, the 443 MW Makiling-Banahaw (Mak-Ban) field is around 7 km southeast of the Maibarara field (**Figure 1**).

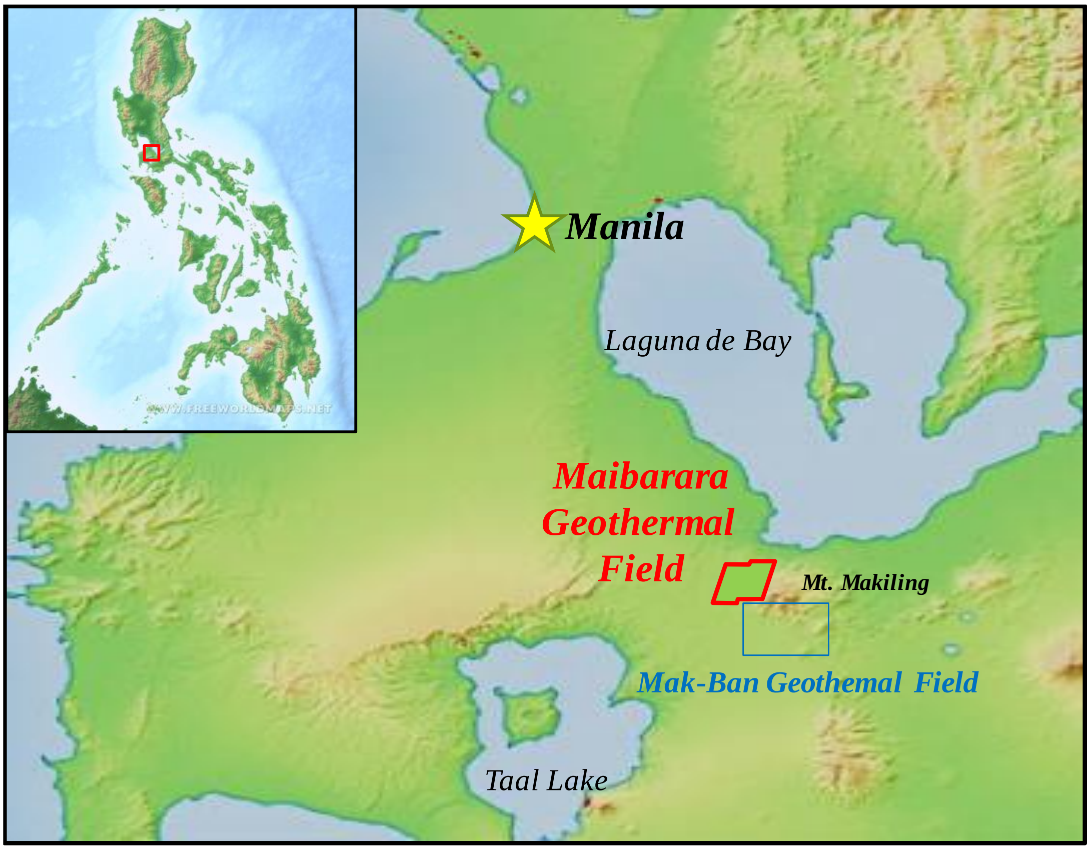

Figure 1: The Maibarara Geothermal Field is about 70 kms southeast of Manila and 7 kms NW of Mak-Ban Geothermal Field.

The Philippine Commission of Volcanology initially carried out early exploration activities in Mt. Makiling and vicinity in early 1970s (Delfin, 2009). The Philippine Geothermal, Inc. (PGI), a wholly owned subsidiary of Unocal, Inc. and developer of the Mak-Ban Field, continued the exploration activities leading to the drilling of 12 deep exploration wells from 1977 to 1983. Exploration drilling by PGI delineated a productive geothermal area in Maibarara of about 2.5 km^2 (**Figure 2**) and an estimated power capacity of 12 MW (Buban et al. 1994). Development of Maibarara, however, was set-aside when PGI pursued the development of the larger Mak-Ban Field.

In early 2010, the Philippine Department of Energy (DOE) awarded the 16 km^2 Maibarara Geothermal Concession Area to PetroEnergy Development Corporation (PERC). Field development for power generation was concentrated on the proven 2.5 km^2 high temperature (>300°C) resource area (**Figure 2**). In February 8, 2014, the 20 MW Unit 1 power plant of the Maibarara field (M1) was commissioned utilizing geothermal fluids from two Unit 1 production wells, PW-1 and PW-2. Commercial operation of the 12 MW Unit 2 power plant (M2) begun on April 30, 2018, thus, increasing the total production capacity of the Maibarara Field to 32 MW. Steam for the M2 is supplied by the excess steam of M1 production wells and steam from well PW-3.

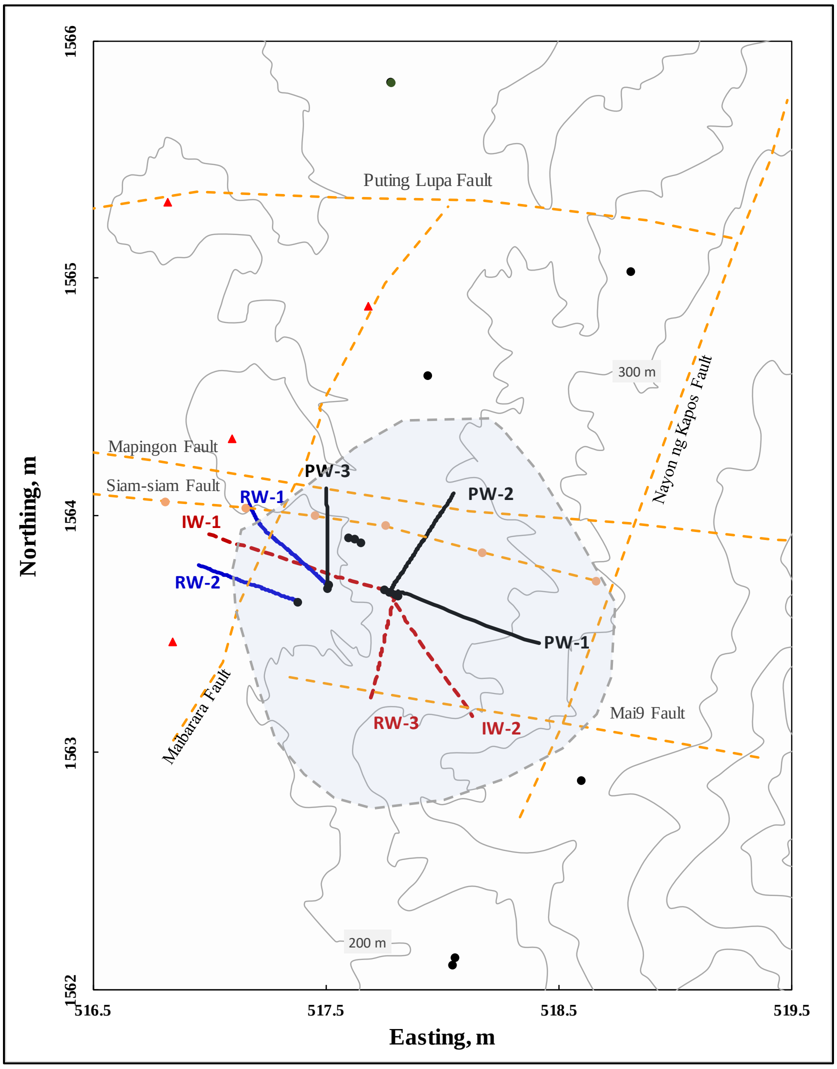

Figure 2: Map showing the Maibarara proven resource area (shaded region), production wells (black line), current injection wells (blue line) and stand-by injection wells (maroon dash line).

The Maibarara geothermal power project was developed where the steamfield and power plant sites were built in a very compact area covering a land area of 7 hectares (**Figure 3**). Since the production wells and the separator are situated in the same pad, the two-phase lines are relatively short. The power plant was built around 100 meters away west of the production pad, thus the shorter steam line was constructed. The reinjection system was designed to be a hot reinjection scheme where the hot separated brine at temperatures of around 162°C will be directly injected into wells IW-1 and IW-2. Wells IW-1 and IW-2 are both are situated on the same pad as the production wells hence the field has also shorter injection lines.

Like all the production wells in Maibarara, reinjection wells IW-2, IW-1, RW-1 and the succeeding reinjection wells are drilled in the postulated upflow zone of the field. Well IW-2 was drilled towards the southeast to a depth of around -1400 m intersected reservoir temperatures between 240 – 250°C at its feedzones. Well IW-1 was drilled to the west a depth of -2400 m intersected formation temperatures of 300°C at its major permeable zone. Condensate injection well RW-1, which was drilled towards the northwest, intersected formation temperatures at 260°C. The high formation temperatures of the reinjection wells has a significant effect on the reinjection capacities of the planned hot brine wells IW-2 and IW-1.

The reinjection system of Maibarara was initially designed to be a hot reinjection scheme (**Figure 3**) where the 162°C separated hot brine is injected directly into the reinjection wells. During the steamfield commissioning of M1 in the second half of 2013, decreasing reinjection capacities of IW-2 and IW-1 were observed. The reinjection capacities were consistently declining during hot brine injection. A series of cold injection tests were done to prove that the wells had better acceptance at lower brine temperatures and this provided the conclusion to switch to cold reinjection system (Maturgo et al. 2015). The separated brine was diverted to the dump silencer and collected into the thermal pond to cool down before it is injected with the use of brine pumps.

The effect of change in injection temperature to the injection capacity or injectivity has been studied and published by several authors including Ariki and Hatakeyama (1998), Gunnarsson (2011), Grant et al. (2013) and Siega et al. (2014). The above authors showed that the well's injectivity is temperature-dependent where injecting low temperature fluids increases injectivity. Gratn et al., (2013) stated that the increase or decrease of injectivity is due to the thermal expansion or contraction of the reservoir rock, respectively. Siega et al. (2014) also concluded that the injectivity is reversible with change in near wellbore temperature assuming that there are no other factors influencing injectivity.

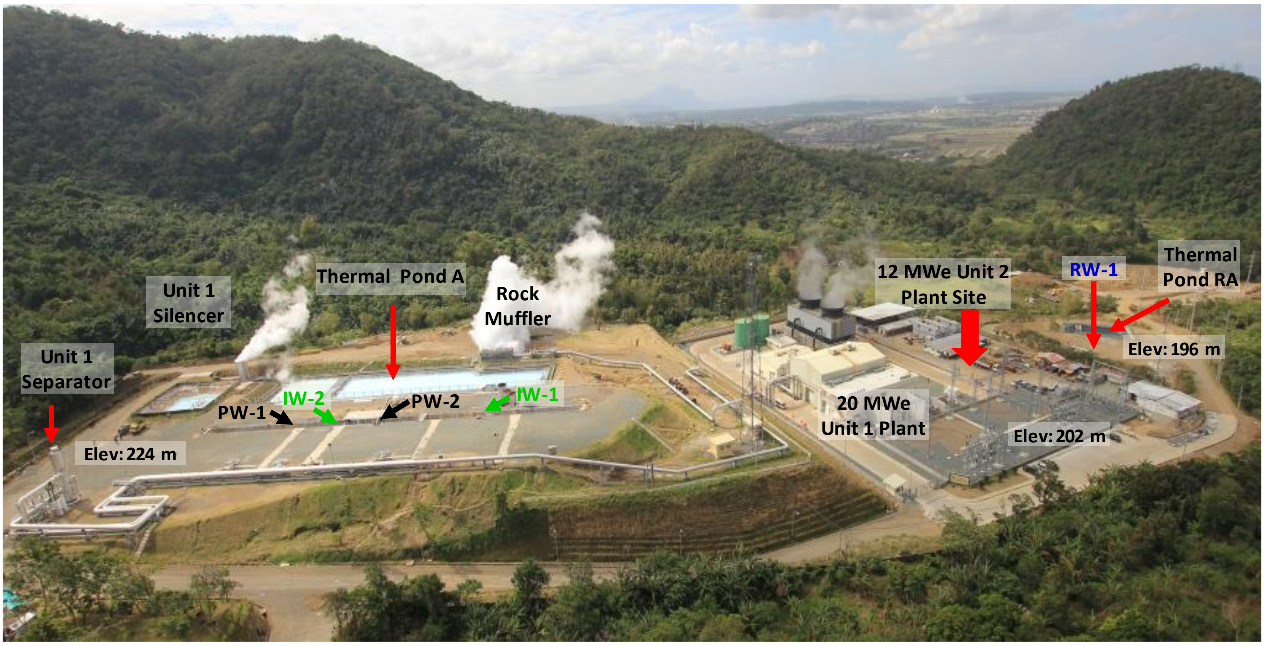

Figure 3: Maibarara field 20 MW steamfield and power plant site where the original reinjection system was designed to reinject the separated hot brine directly into IW-1 and IW-2 (green font). Plant condensates are injected into RW-1 (blue font).

2. BRINE REINJECTION MANAGEMENT

2.1 Reinjection Schemes during the 20 MW Operation

2.1.1 Brine Injection into IW-1 and IW-2

Well IW-2 was first used as a cold injection well during the flow testing of IW-1 in 1982 and was mechanically workover in 2011 when PERC took over the Maibarara Field. IW-1 was the primary cold injection well during the flow testing of PW-1 and IW-2 in mid-2011 and of PW-2 in 2012. IW-1 had been continuously used as cold injection well from 2011 to mid-2013 when PW-1 and PW-2 were put on-bled after their respective flow testing. IW-1 had to be mechanically re-worked in September 2013 to clear the mineral scales that resulted from the cold brine injection.

Figure 4 shows the injectivity trends during of wells IW-2 and IW-1 in response to changes of injection temperatures. The injectivity of the injection wells while in operation is calculated from wellhead pressure (WHP) using the relation:

$$WHP = P_r - \rho_w gZ + Q/II + CQ^2$$

where Pr is the reservoir pressure, Q is the injection rate, II is the injectivity and CQ^2 accounts the pressure drop due to frictional losses along the casings (Grant and Bixley, 2011). Both wells showed significant decrease in injectivity during hot brine injection compared to their post-workover injectivity.

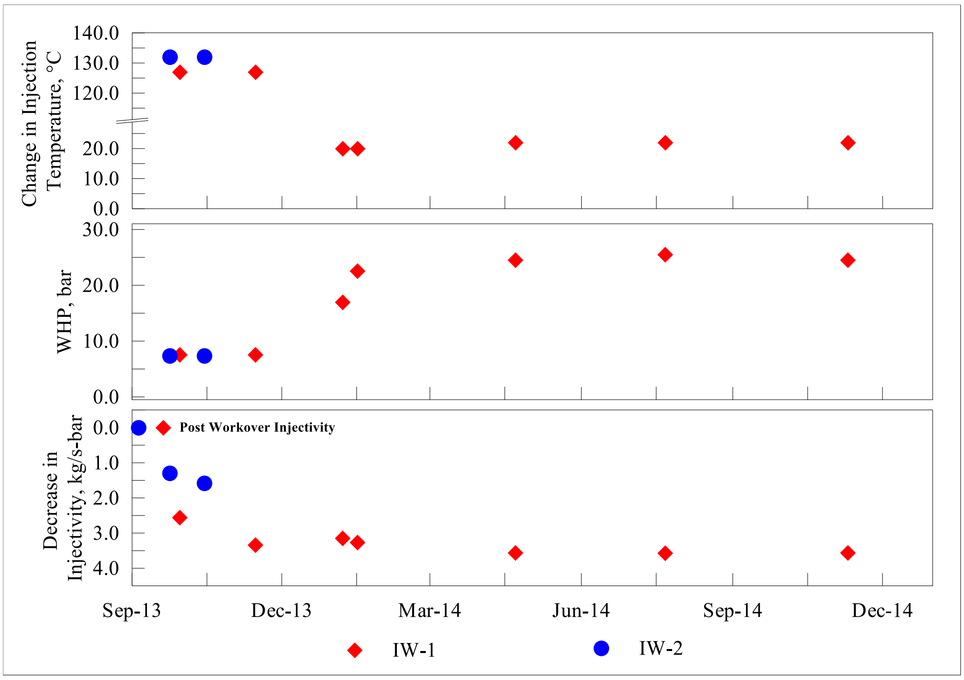

Figure 4: Trends of injectivity change of IW-2 and IW-1 against changes injection temperatures.

Maibarara switched to a cold reinjection scheme (**Figure 5**) because of increasing WHP of the injection wells during hot brine injection. After dumping the brine into the thermal pond, fresh water is added to help cool the brine at the same time dilute the silica before reinjecting using brine pumps. Pumping of the cold brine was intermittent since there is low brine flow from production wells.

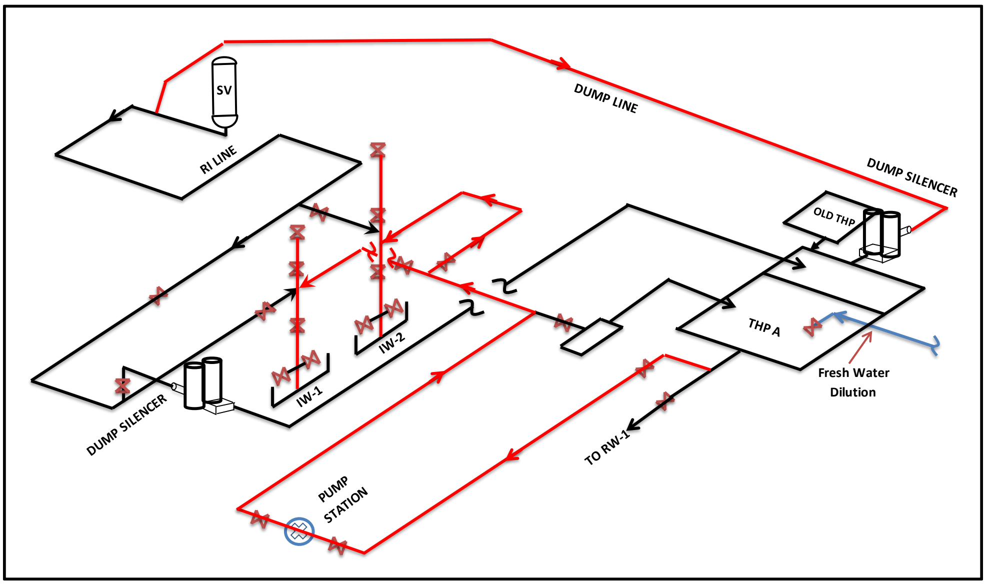

Figure 5: Cold reinjection scheme on IW-1 and IW-2.

Even with the cold brine injection scheme, there was no observed significant improvement in the injectivity of IW-1. There was a slight increase on the well's injectivity right after the adoption of cold injection scheme but through time, its injectivity decreased. IW-2's capacity was also observed to be decreasing with time. The initial decreasing trend in injectivity may be due to silica that were deposited in the permeable zones of the two wells when they were used as injection wells during the flow testing of production wells, IW-2 in 1983 and IW-1 from 2011 – mid 2013. Probing surveys in late 2014 tagged scale obstructions at the wellbore of these injection wells that also add to the reduction of their injectivity.

2.1.2 Reinjection into Well PW-3 and RW-3

Drilled on the 3rd quarter of 2014 at an elevation 28 m below the production pad well PW-3 was designed to replace injection wells IW-2 and IW-1. The well intersected formations of high permeability and temperatures >320°C. Injection of cold brine commenced in November 2014 where diluted brine from Pad A thermal pond was injected into the well by gravity, thus pumping was eliminated. Reinjection at PW-3, however, was short lived (3 months reinjection period) when Maibarara decided to convert the well into a production well for the M2 plant.

Well RW-3, which was drilled after PW-3, was collared at Pad A and is intended to be the production well of M2. But because of its low permeability and poor productivity the well was converted into an injection well. Cold brine injection into RW-3 begun on March 2015 using the original cold reinjection scheme with minor modifications (**Figure 6**). Well RW-3 was the main cold brine injection well while well IW-2 was used intermittently use. Injection brine temperature was maintained between 54 – 57°C.

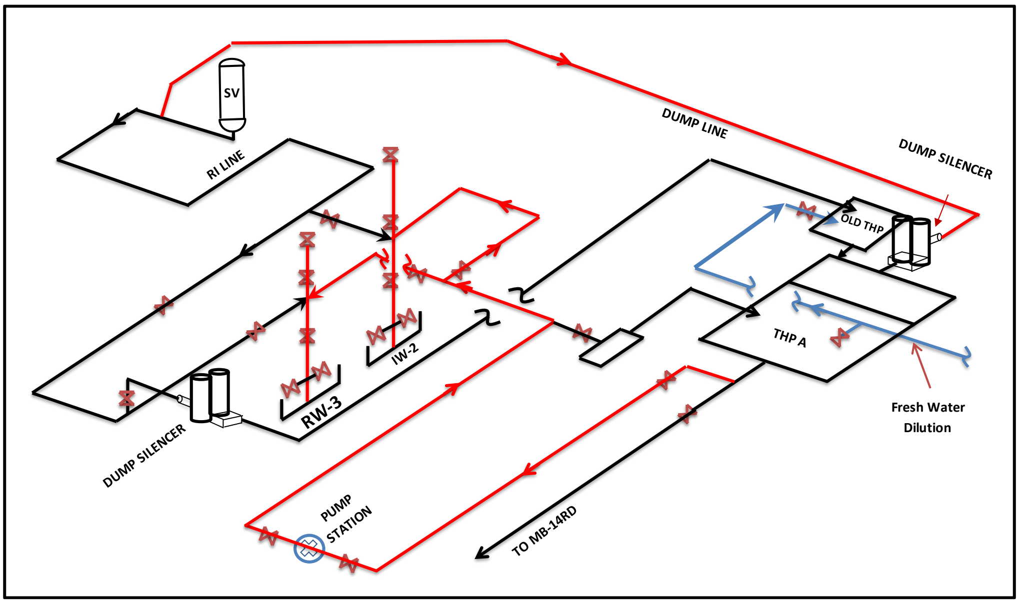

Figure 6: Cold reinjection scheme using RW-3 as the main cold brine injection well.

High wellhead pressures (> 20 bars) were initially encountered during brine injection indicating the poor acceptance of RW-3. Wellhead pressure of RW-3 begun to drop starting September 2015 and there was a corresponding increase in the injectivity of the well (**Figure 7**). Unlike in IW-1 and IW-2 where brine injection was done intermittently, continuous brine pumping (24 hrs daily) was done at RW-3. This continuous cold brine injected into RW-3 caused thermal contraction of the reservoir rock inducing fracturing resulting to the increase in the well's injectivity. Reinjection at RW-3 was ceased in August 2016 when tracer test confirmed the well's connection to production well PW-2 (Marzan, 2020).

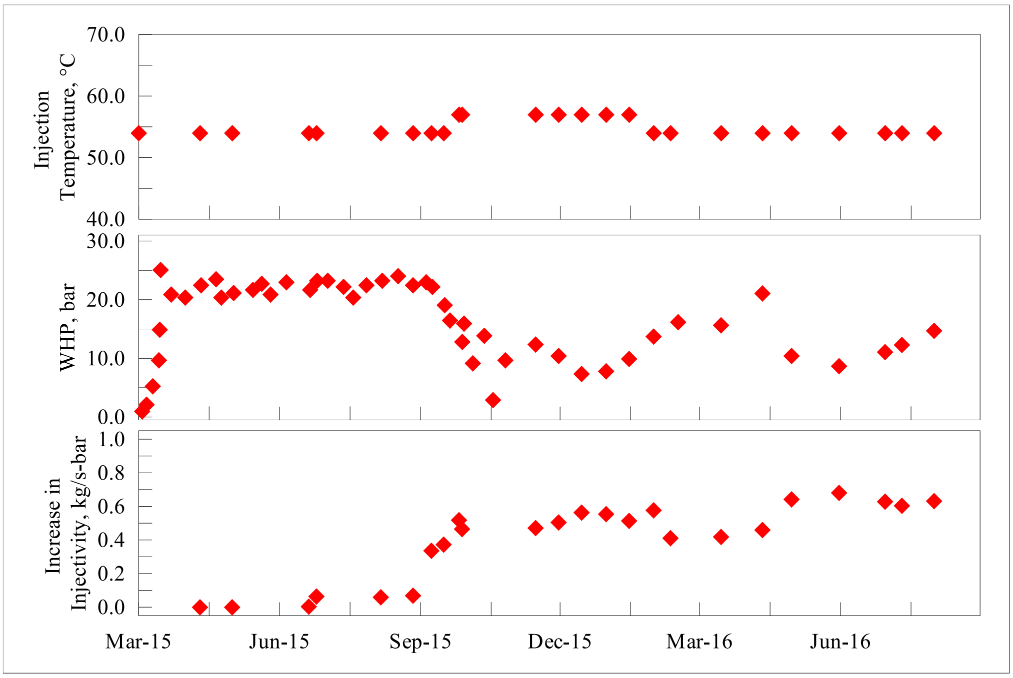

Figure 7: Well RW-3 injectivity and operating parameter trends. Increasing injectivity indicates thermal stimulation on the well's fractured zone.

2.2 Reinjection Schemes in the 32 MW Operation

Well RW-2 was drilled in mid-2016 to provide additional reinjection capacity for the 12 MW expansion for Maibarara. The well, however, have poor injection capacity in spite intersecting geologic faults that are intersected well IW-1, which has a relatively good injectivity. Due to well RW-2 poor acceptance, well RW-1 became the main cold brine injection well.

From the experience gained in cold brine injection in the early years of operation, improvements in the reinjection system were adopted such as building perimeter canals along the sides of thermal ponds, construction of two additional brine pond and a long brine canal. Since RW-1 and RW-2 are located below the power plant, the cold plant condensates is now mixed with the brine prior to injection thus eliminating brine dilution with fresh water (**Figure 8**). The objective of these enhancements is to lower the injection temperature to optimize the injectivity of both wells. A study on the injectivity of the wells indicate that their capacity can be optimized if the injection temperature is below 50°C (**Figure 9**). With the system enhancements made, the cold brine is reinjected at temperatures of around 40°C.

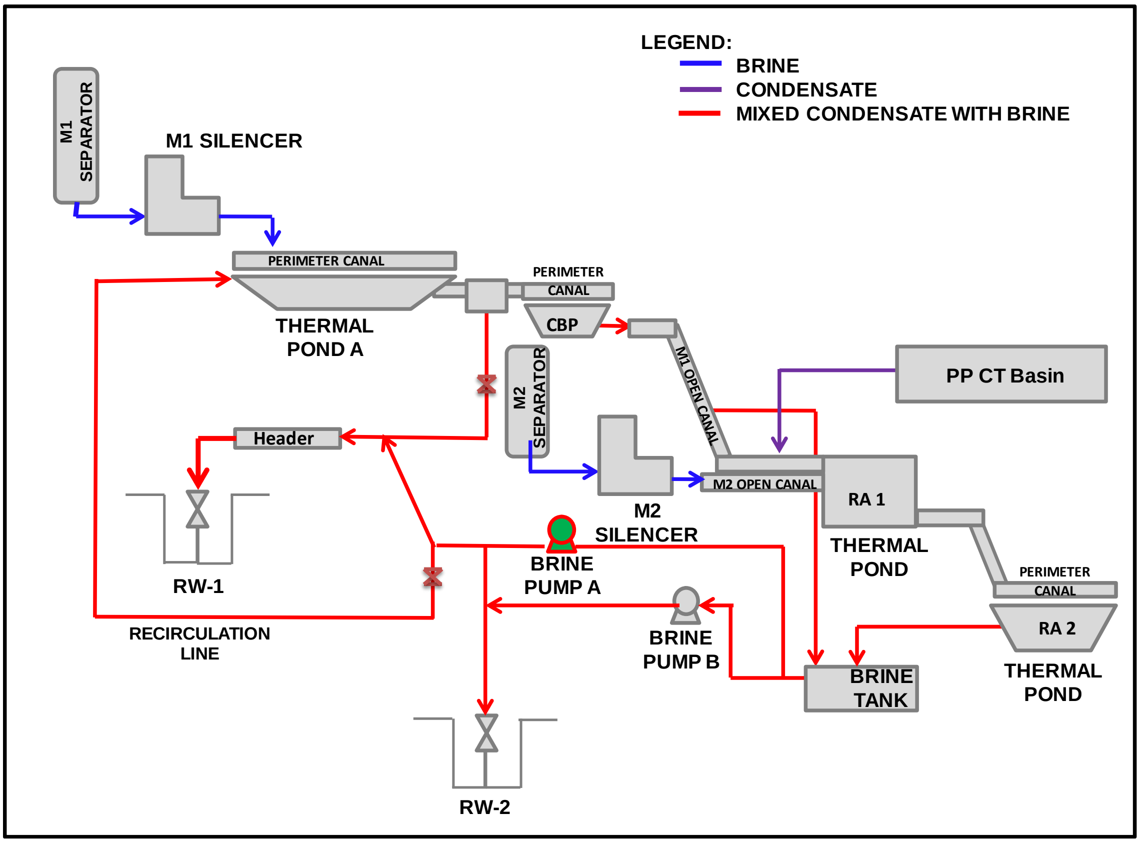

Figure 8: The 32 MW cold brine reinjection where well RW-1 as the main reinjection well. Brine from the production wells is mixed with the power plant condensates before pumping into the injection wells.

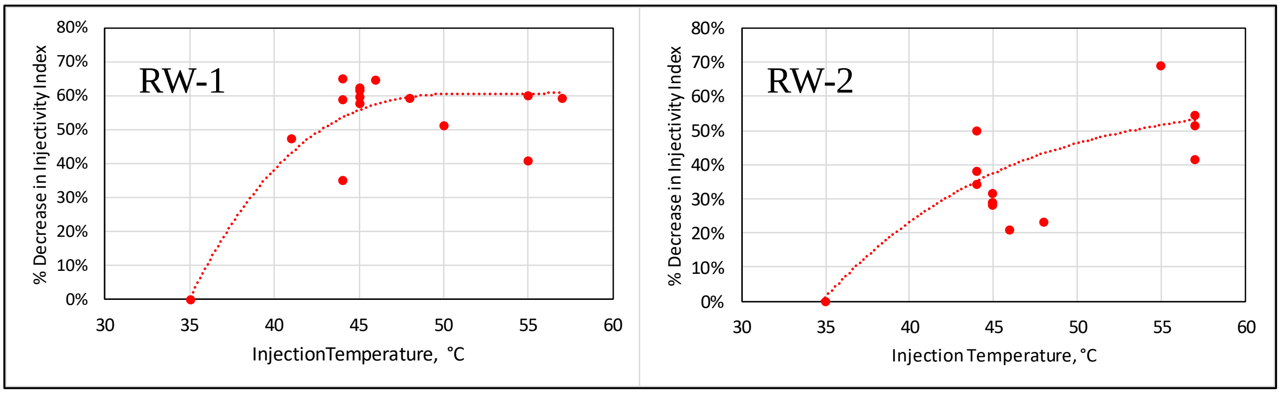

Figure 9: Injectivity trends versus injection temperatures of wells RW-1 and RW-2 where optimum injectivity can be attained at injection temperatures below 50°C.

3. CONCLUSIONS

Reinjection of geothermal brine has been an operational and resource management challenge in Maibarara. The planned the hot brine reinjection proved to be unsuccessful thus, a cold brine reinjection scheme was adopted. The major operational task in the cold scheme is to reduce the injected brine temperature to maximize the injection capacity of the reinjection wells. Determining the operational injectivity index is a big help in determining the optimum injection temperature. Continuous cold brine injection enhanced the injectivity of a well as proven by RW-3. Its proximity to the production area, however, induced reinjection breakthrough.

The optimization of the reinjection system in Maibarara evolved from the experience gained during the initial years of operation of the system. Enhancements were done and these proved to be successful as they improved the injection capacity of the reinjection wells.

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