

Innovative Recharge Heat Recovery Project: Retrieving Steam One Drop at a Time

Irene Marice Fernandez, Marie Hazel Uribe, Katrina Dacillo and Jericho Omagbon

Energy Development Corporation, 6th Floor Rockwell Business Center Tower 3, Ortigas Avenue, Pasig City, Philippines

fernandez.ia@energy.com.ph, uribe.mhc@energy.com.ph, dacillo.kb@energy.com.ph, omagbon.jb@energy.com.ph

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ABSTRACT

The Tongonan Geothermal Field has been providing clean energy to the Philippines for four decades. This long period of production has resulted in pressure drawdown, boiling and deepening of the water level to depths way below the reach of 43% of the wells; thus, constraining their production within the steam zone of the reservoir. The steam zone of the field has also reached the phase of superheating, starting from the areas near the upflow region. In order to adapt to this emerging reservoir process, the Innovative Recharge Heat Recovery (IRHR) program was created for operational sustainability. Trickle injection is one of the key initiatives that has proven to be effective in managing the effects of superheating. Controlled amounts of 10-15kg/s of power plant condensate are injected into shallow, infield wells to generate additional steam via secondary heat extraction and provide pressure support. An alcohol tracer test was also conducted to map out the reach of the trickle injection.

1. INTRODUCTION

Leyte is one of the main islands of the Eastern Visayas region in the Philippines that is often visited by a few typhoons which are getting stronger each year due to climate change. Renewable sources of energy are a key component in decreasing the dependency on fossil fuels. Thus the presence of the Tongonan Geothermal Field (TGF) with an installed capacity of 485MW has proven to be a beneficial solution to the island. The Tongonan Geothermal field is divided into three sectors: (a) Upper Mahiao that has a 132 MW binary power plant (UMPP), (b) Tongonan-1 that has a 120.5 MW main power plant (TGPP) and an topping-cycle optimization plant (T1TCP), and (b) Malitbog-South Sambaloran that has a 232 MW main power plant (MBPP) and a bottoming-cycle optimization plant (MB BCP) (Fig.1). The Tongonan-1 sector was the first to be developed and produced with the commissioning of the TGPP in 1983 and the rest of the sectors became commercially operational from 1996-1997 (Dacillo, et. al, 2010). Initially, the mass extraction in the Tongonan-1 sector was only one million tons per month with 50% of it reinjected back as separated brine and power plant condensate (Fig. 2), (Dacillo, et. al, 2010). With the addition of the two other sectors in 1997, the mass extraction from the TGF increased to five million tons each month with 40-50% of it reinjected back, (Dacillo, et. al, 2010).



Figure 1. Location map of the Tongonan Geothermal Field with the three main power plants taken from Google Maps.

New changes in the reservoir after 40 years of producing clean and renewable energy is being observed in the recent years. The initial reservoir response was a fieldwide pressure decline, which also resulted in boiling within the reservoir, that eventually led to the deepening of the water level. Most of the wells drilled have shallow total depths up to 1500-2000 mMD; thus, when the water level dropped, almost half of the production wells were left producing only from the steam zone. With most of the mass being extracted is in the form of steam, the reinjected brine back to the geothermal reservoir has also decreased to 20-30% of the mass extracted (Fig. 2); eventually leading to superheating within the TGF.

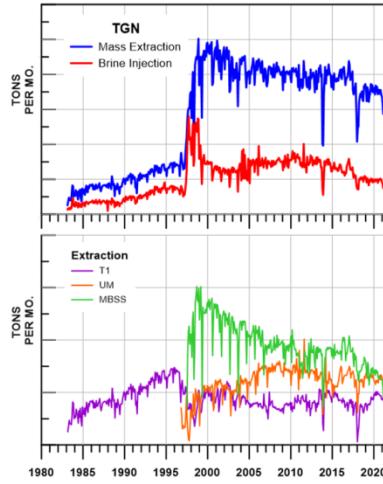


Figure 2. Mass extraction vs brine injection in the Tongonan Geothermal Field from 1983-present (top). Mass extraction in TGF per sector from 1983-present (bottom)

2. SUPERHEATING IN THE TONGONAN GEOTHERMAL FIELD

Superheated steam is defined as steam having a temperature greater than the saturated temperature (T_{sat}) at a certain steam pressure (Fig. 3). The initial mechanism of superheating within geothermal reservoirs was described by Truesdell and White (1973) as an after effect of boiling in the reservoir due to pressure drawdown. When the pressure within the reservoir drops, this causes the liquid water in the rock to boil off and transfer its heat energy to the rock (Truesdell & White, 1973). After some time, the rock becomes dry but heated that when another batch of steam will pass through the rock, the rock transfers its excess heat to the steam, causing the steam to be superheated when it reaches the geothermal wells (Truesdell & White, 1973).

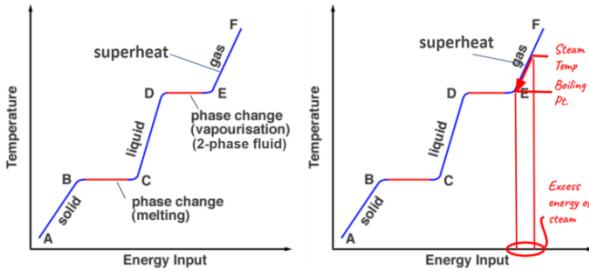


Figure 3. Phase diagram of water at constant pressure (left) with the excess energy of superheated steam highlighted (right)

This simple mechanism of Truesdell and White (1973) was further elaborated by Hanano (2021) to include the concept of relative permeability and coming up with two mechanisms. The first mechanism involves the production of superheated steam from an immobile liquid phase once the water saturation is below 0.3 (Hanano, 2021). When the trapped, immobile water boils it becomes saturated steam which eventually becomes superheated when it flows towards the production wells as it is further heated by the rocks along the way (Hanano, 2021). The second mechanism by Hanano (2021) shows that superheated steam can also form from a flowing two-phase fluid. The two-phase fluid is located far from the production well, as it flows towards the well, the pressure and the temperature of the fluid begins to drop eventually leading to flashing within the fluid and decreasing the saturation of water (Hanano, 2021). This leads the flowing enthalpy of the fluid to increase together with its volumetric rate; eventually before it reaches the well, the two-phase fluid becomes a fully dry steam (Hanano, 2021). It then becomes superheated as it due to the decreasing pressure it encounters as it flows towards the feed zone that once it enters the well the previously two-phase fluid, which turned into an isothermal dry steam, has finally become a superheated steam upon entering the well (Hanano, 2021).

The extent of superheating in the TGF is observed in the central part of the field (Fig. 4). However for the Tongonan-1 sector, not all wells are dry; rather there are still some production wells that have two-phase fluids – those that are deep enough to tap the water level with TDs at 2500-3000 mMD and those that are near the reinjection sink and are availing the permeability of known brine conduits. Thus, it is highly likely that the second mechanism of Hanano is what is currently happening in TGF. This is collaborated by the geochemistry of the water component of some of the deeper wells are similar to that of reinjected brine. The TGF is not completely drying out as there is evidence of reinjected brine flowing back to the reservoir. The widening distance between the feed zones of dry wells and the depth of the two-phase fluid is one of the reasons that the dry wells get superheated steam.

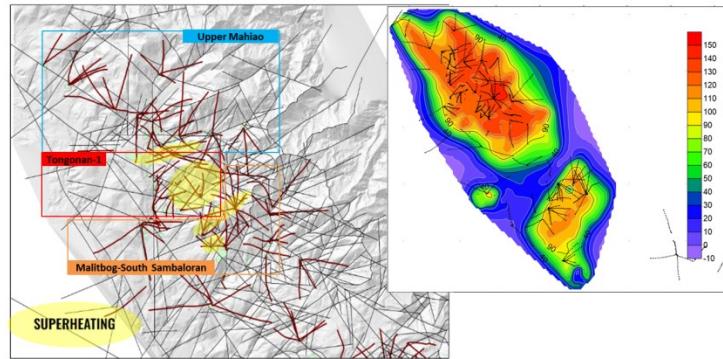


Figure 4. Map showing the of Superheated areas of the Tongonan Geothermal Field and its respective sectors (left) based on the dual porosity model in Tetrad (right).

Dealing with superheated steam is a big challenge especially for the surface components that would convert it to energy. It has been observed that the dry wells of TGF tend to also have high total suspended solids that can cause erosion not only of the wellhead components but also of the surface facilities. Aside from erosion, superheated steam can also cause corrosion as it can generate hydrogen chloride (HCl) gas (Hanano, 2021). Based on the mechanisms discussed above, the main source of the excess energy in superheated steam is the hot reservoir rock. The idea of introducing small amounts of liquid directly into the reservoir rock to feed off its excess heat and generate additional steam serves as one of the driving principles of the IRHR Program.

3. INNOVATIVE RECHARGE AND HEAT RECOVERY PROGRAM

Aside from harvesting excess heat from the rocks, the IRHR Program also aims to prevent further decline in steam production because of pressure and mass drawdown. The metrics of success of the program will be measured by the improvement in the steam and liquid pressure and a significant net increase in the output of the nearby affected production wells. To achieve these objectives, the program involves conversion of marginal production wells into trickle injection wells or deliberate drilling of shallow trickle injection wells in strategic locations.

These trickle injection wells are targeted infield, near the affected production sector. Since the rocks around these production wells are the ones that are superheating the steam, a targeted injection of small amounts of liquid into these rocks can recover some of the excess heat and produce additional steam (Fig. 5). Given that the injection is infield, the additional steam produced need only to travel a shorter distance to the feed zone of the production wells so there is less chances of it becoming superheated. And since there are now additional fluids taking off the excess heat energy from the rocks, this decreases the amount of excess heat energy that can superheat the steam coming from the distant two-phase fluid. The operative word is also “trickle”, which means that only small amounts of fluid (10-15 kg/s) must be injected into the well in order to prevent cooling and collapsing of the steam zone. The optimum depth for a trickle injection well is just enough to reach the superheated region of the reservoir and not the deep liquid zone. For the whole project to fully achieve its potential there needs to be a network of optimally situated trickle injection wells within the whole TGF.

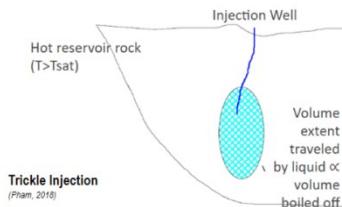


Figure 5. The main idea behind a trickle injection well is that the small volume of liquid injected by the well directly on the hot reservoir rocks will turn into additional steam.

Initially, the preferred wells for trickle injection are non-commercial wells that are located near or within the superheated areas as a proof of concept and to save up on drilling costs. After these non-commercial wells have been identified, numerical modeling via ECLIPSE* would be done in order to verify its viability and simulate its impact on the nearby wells. This step is valuable in filtering out candidates that can cause cooling or have no impact at all. Once the simulation is completed and the well candidate is deemed viable, an acceptance test is done to check whether the non-commercial well still has the capacity to accept 10-15 kg/s of fluid. Power plant condensate became the preferred fluid over separated brine as it is less prone to scaling and is cooler; thus, it can mine more excess heat

than brine. Once all the operational nuances are put in place, the trickle injection well is then commissioned and the monitoring of its real impact on the nearby wells begins.

3.1 Results of Trickle Injection

Well-A was commissioned as a trickle injection well within the Tongonan-1 sector in on September 2020 via quenching (Fig. 6). After the well was successfully quenched and put in vacuum it was fully cut-in with power plant condensate injection. However, after 2 months, there were interruptions due to several leaks in the main alvenius lines used for condensate conveyance. After a day of repairs, the well was successfully cut-in again and the flow rate was maintained at 14-15kg/s to prevent from starvation. A wye-connection to the condensate line was installed to provide an option to switch to fresh water injection should there be any disruptions on the conveyance of power plant condensate in the future. To monitor the flow rate, an automatic flowmeter was attached to the main condensate line and its results were checked with regular ultrasonic flow measurements (UFM) and tracer flow test (TFT) measurements. Based on the ECLIPSE * Model, a flow rate of 15 kg/s would be more sustainable to the field in the long run than a higher load of 30 kg/s with a significant increase in steam flow within five years from the start of injection (Fig.6).

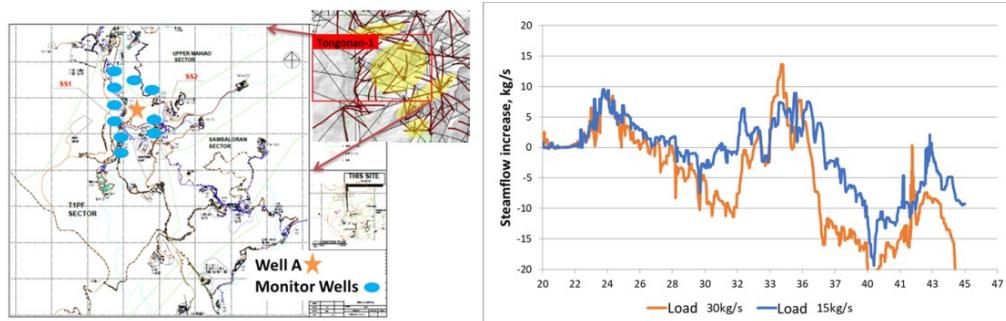


Figure 6. Location Map of Well A and its monitor wells (left). ECLIPSE* Model on the impact of different injection loads at Well A to the nearby monitor wells (right).

The selected monitor production wells are those that are within a 500 m radius from Well-A, both with direct and possible indirect fault conduits. Monthly TFT measurements were taken to measure effects in the output of the monitor well, together with gas samples to monitor certain geochemical parameters for signs of cooling. Thermowell measurements were also regularly taken to measure the extent of superheating. As predicted by the model, there was no significant increase in the total output of the monitor wells (Fig. 7). However, it was observed that the decline rate improved for the duration of the trickle injection (Fig. 7). The pre-trickle injection decline rate was initially calculated (blue line) and further extrapolated (blue dashed lines) in Fig. 7. Comparing the slope of the blue line with that of the orange line, which is the observed post-trickle injection decline rate, there is a gradual decrease in the slope signifying an improved decline rate from the nearby wells after a year of trickle injection (Fig. 7). The geochemical trend also does not show any signs of cooling in the monitor wells; however, the degree of superheating for these wells remains high at 20-40°C (Fig 7).

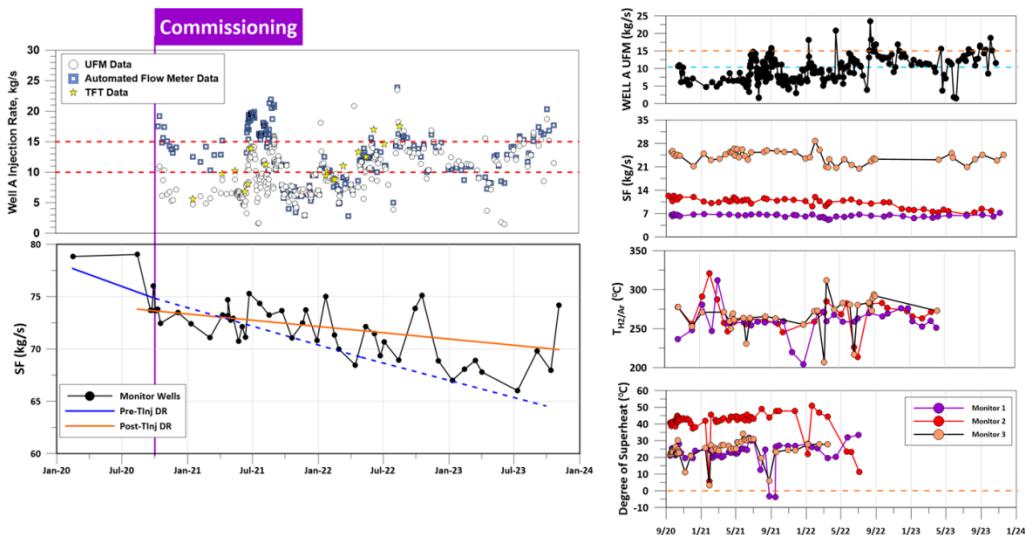


Figure 7. Well A Injection Flow rates against the Total Steam flow (SF) of the monitor wells showing Pre-Trickle Injection and Post-Trickle Injection Decline Rates (left). Sample physical and geochemical data from 3 monitor wells – degree of superheat, geothermometer based on hydrogen and argon ratios and individual steam flows (right).

3.2 Alcohol Tracer Test

In order to further evaluate the impact of the trickle injection in Well-A, an alcohol tracer test was included in the project. Alcohols have been used successfully as a two-phase tracer in the Matsukawa Geothermal Field in Japan (Fukuda, et. al, 2005). Alcohols were deemed as suitable tracers due to their high solubility in water and they can partition into both the vapor and liquid component (Fukuda, et. al, 2005). The alcohols used as tracers in Matsukawa were ethanol, isopropanol and different mixtures of the two (Fukuda, et. al, 2005). For the tracer test in Well-A, it was decided to use isopropyl alcohol as it was less flammable than ethanol. On January 2023, 1300-gallons of 70% isopropyl alcohol was injected in Well-A at a rate of 90-113 gallons per minute. UFM readings of Well-A taken during the tracer test assured that there is a 12 kg/s of condensate flow in the well. Well-A remained at vacuum condition for the duration of the tracer injection.

Due to analytical constraints, not all monitor wells have complete data sets. Only Monitor Well 1 has sufficient data for tracer inversion and simulation as it was prioritized after showing a positive tracer response 12 days after the injection. Monitor Well 1 had a total tracer recovery of 14% along a flow path distance of 350m. The cooling curve for Monitor Well 1 was further calibrated using its recorded T_{H2Ar} data for the duration of the trickle injection (Fig 8).

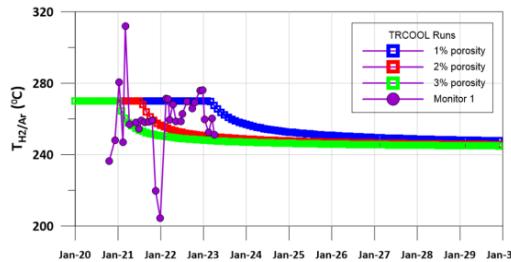


Figure 8. Calibration of the cooling simulation of Monitor Well 1 based on the tracer recovery results.

4. CONCLUSION AND RECOMMENDATIONS

With the drastic effects of climate change manifesting globally, there is a need to find sustainable solutions to extend the productivity of geothermal systems that have been exploited for more than 40 years. While the geothermal resource remains renewable, it is not without challenges. Superheated steam is one of the main challenges that are faced in the Tongonan Geothermal Field as the decades of mass extraction has led to pressure drawdown and deepening of the water level. In an attempt to mitigate superheating, the Innovative Recharge and Heat Recovery Program was initiated, with the Trickle Injection Wells as one of its projects. Well A being the first trickle injection well in the Tongonan-1 sector have proven to be beneficial in arresting the decline rate of the nearby wells. However the full benefits of trickle injection wells cannot be achieved with only Well A; thus it is also important to add other trickle injection wells that would make a network within the TGF that would harness the excess heat in the reservoir rocks and reduce the superheating of steam. Should the commissioning of non-commercial wells be a problem or cause of delay, it would also be better to pivot towards drilling shallow slim hole wells for targeted trickle injection considering the positive results from Well A.

The use of numerical modelling such as ECLIPSE* simulations is an essential step to guide the choice of location and direction of the trickle injection wells whether they are non-commercial ones or to be drilled in the future. Tracer tests are also important in the evaluation of the extent of effects of the trickle injection to its nearby wells.

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