Utilization of Wells with Former Acidic Fluids: A Palinpinon Geothermal Production Field Experience

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ABSTRACT

Steam production has been obtained from a number of wells with acidic fluids that were initially not utilized for commercial production in the Palinpinon Geothermal Production Field located in Negros Island, Philippines. Based on chemistry, the discharged fluids of these wells are of acid-sulphate type with no magmatic origin. Geographically, most of these wells are located near the postulated upflow area. Continuous field exploitation has induced pressure drawdown in the field, resulting in lowered water levels in the production sector. This caused some of the production wells to dry up, eliminating the acid feed. This also promoted incursion of reinjected fluids that suppressed the source of acidity in some of the two-phase wells. Succeeding steam augmentation initiatives were based on this experience which led to further drilling towards upflow area. During the discharge tests and production, new wells drilled toward said area discharged fluids with similar characteristics as the neutral wells in the field. Occasionally when these wells were shut or throttled, the initial discharging fluids had low pH but eventually turned neutral with continuous discharge. This experience showed that acid fluids still persist thus adherence to optimal reinjection strategies as well as proper well utilization play a vital role in sustaining steam supply from these acidic wells..

1. INTRODUCTION

The Palinpinon Geothermal Production Field has been operating for more than 35 years. Sustaining the required steam flow was challenging through the years due to different reservoir processes interacting through continuous field exploitation. One of these challenges was the inflow of low pH fluids to some production wells that were later on utilized due to favorable geochemical changes. The cut-in of these former acidic wells increased the steam available of the field. This paper will provide relevant observation during the intrusion of acidic waters.

The field is also known as Southern Negros Geothermal Field (SNGF) and is located in Negros Island, in the central part of Philippines (Figure 1). It is situated in a volcanic terrain; on the north is Mt. Guinsayawan and Cuernos de Negros on the south. The postulated upflow is to the north of the volcanic centers towards the bottom of the production wells and the outflows is to the northeast towards Palinpinon-1 and northwest towards Palinpinon-2 wells divided into three sectors: Balasbalas, Nasuji and Sogongon. All of the mentioned former acidic wells are located within the upflow area of the field, as represented by thick green lines in Figure 2.

There are four power plants with a total installed capacity of 221.9MWe. The steam requirement is supplied by more than forty (>40) production wells and eight (8) of these have previously acidic inflow. Three (3) wells are supplying steam in Palinpinon-1 (i.e. K10, P20 and P22), two (2) wells in Nasuji (i.e. J1 and J6) and one (1) well in Balasbalas (B1). These wells were drilled in 1982 to 1983 except for B1 which was drilled in year 1990.

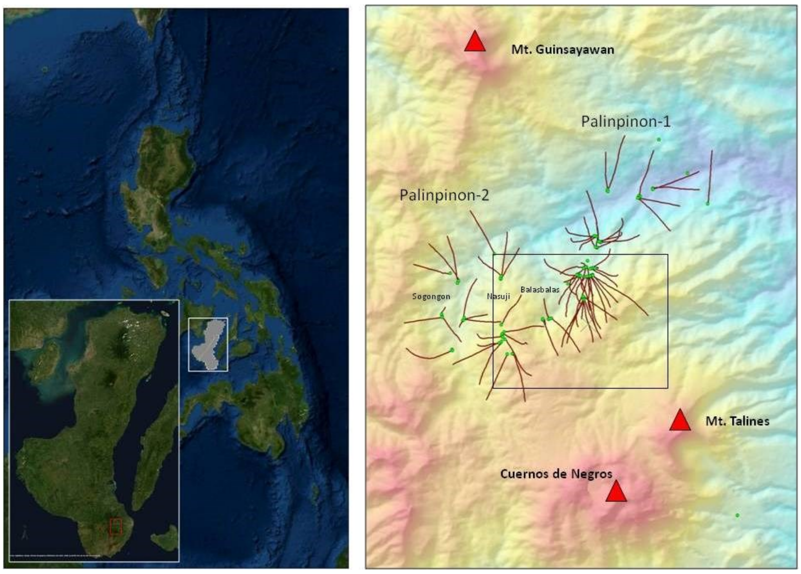

Figure 1: Negros Island, Philippines (left) and Southern Negros Geothermal Field (right).

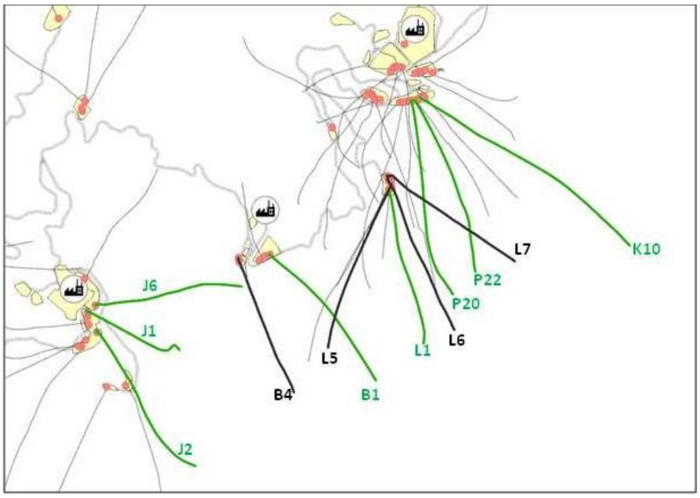

Figure 2: Location of former acidic wells (thick green lines) and relatively new wells (thick black lines).

2. EARLY ENCOUNTER OF LOW PH (1982-1984)

Since the start of exploration drilling in 1976 until start of commercial operation of Palinpinon-1 in 1983, most wells are discharging near neutral to neutral pH except for one well, J2. Its pH ranged from 3.25 to 3.62 during its seven (7) days discharge then the well was shut. Its offset wells J1 and J6 are discharging neutral pH but shows a decreasing trend although its lowest pH during testing did not reach that of J2. Other offset wells to the west showed consistent neutral pH while offset well to the south did not sustain discharge. A downhole sampling was then conducted for J1and J2. The results did confirm that acidic fluids exist at depths. Lowest pH was 2.83 from well J1 while some feed zones have neutral-pH.

3. CASE HISTORIES

3.1 Acid Inflow in Palinpinon-1

Most of the production wells drilled in this sector produced near neutral to neutral-pH, saline fluids. The chemical signatures of the acidic fluids include very low Chloride (Cl^-) values, high Sulfate (SO_4^{2-}), high Magnesium (Mg^{2+}) and pH values of less than 6.

Well P22 fluids turned acidic after two months of continuous discharge and was eventually shut four months after, and became the first well recorded to exhibit acidic discharge in SNGF. P22, like P20 and K10, was also drilled near the postulated upflow zone. From 1984 to 1993, fluid pH values were consistently low, while reservoir SO_4 showed increasing trends (from ~40 to 150 ppm). Suppression of the acid feed was not successful, and discharge remained acidic even after work over in 1987. Calcium injection experiments conducted to seal off the acid feed were also futile. The well remained shut until 1991 when the well was tested again and discharged neutral, saline-type of fluids. Harper et. al (1985) stated that the anhydrite obstructions in the well is a result of the change in the relative contribution of acidic and neutral fluids to the well discharge. However, acidic discharge was again experienced in P22 on September 2017 when the well was abruptly throttled to its minimum opening. The well discharged low pH (2.92 units: laboratory pH), acid-sulphate (SO_4^{2-} of 282 ppm; previously 27 ppm on average) type of fluids when its wellhead pressure (WHP) rose from 7.7 ksc to 11.3 ksc. This event led to a reduction in well's steam flow by almost 70% (see Figure 4 below). The well was isolated from the system and was continuously discharged to a silencer until fluid pH becomes neutral again. When it was cutin back, its steam flow did not immediately show improvement but minimal changes quarter after quarter has already been observed.

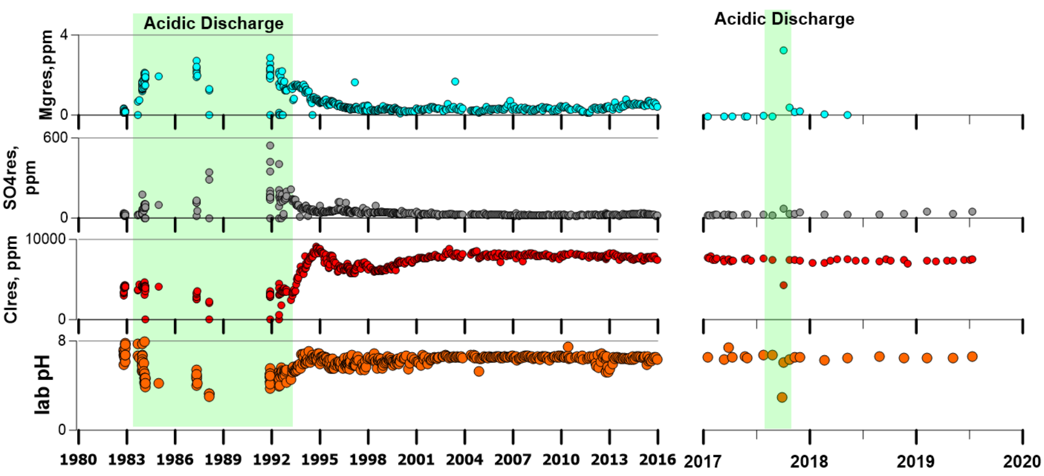

Figure 3: Well P22 selected geochemical parameters.

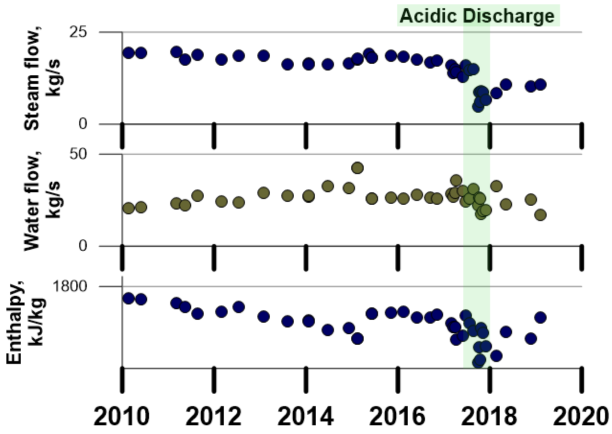

Figure 4: Well P22 physical parameters.

The discharge of K10 initially showed elevated sulphate concentrations (30-60 ppm) but did not manifest very low pH values as compared to P22. This well is also located within the Southeast of Puhagan area. Both P22 and K10 were worked-over in 1987 to clear the wellbore with anhydrite scales and to suppress the acid fluids during production. Just like P22, occasional acidity (pH values of 4 to 5.5) was still observed in K10 after its work-over. Continuous discharge of neutral, high-chloride fluids have started when injection was shifted outfield since 1991 (until present).

Well P20 was first put online in 1983 and sustained discharge until 1990. From 1990 to 1992, P20 was worked-over twice. Petrographic results pointed out that the anhydrite blockage location was just within 1726-1871 mMD RKB where the anhydrite crystals were recovered. The crystallinity and size of the recovered anhydrite crystals indicated that they were formed at a much faster rate or that the possible downflowing acidic fluid did not have enough time to persist within the zone of deposition (Bueza and Hermoso, 1990). When it was utilized back in 1993, discharge fluids suddenly turned acidic, with a pH ranging from 2.98 to 4.83, while reservoir SO_4^{2-} showed sudden increase from 47 to 350-700 ppm in 1993. This sudden change in fluid chemistry may have been due to a change in contribution between the deeper neutral fluid source and the shallow steam condensate layer (as can be supported by an observed increasing enthalpy trend and declining water flow in well P20). It was believed, however, that the downflowing acid waters were suppressed by intrusion of cooler reinjection fluids, rendering calcium-rich, neutral discharge fluids in succeeding years until present.

Another production well situated just north of the postulated uplow region, Well L1, discharged acidic fluids (pH range of 3.19 to 5.80, SO_4^{2-} range of 123 to 466 ppm, reservoir Cl of 492 to 669 ppm) during its discharge test in 1991. The well was never utilized for steam production and was plugged and abandoned in 1992 when results of two (2) Ultrasonic Testing (UT) measurement suggested possible reduction in wall thickness of Well L1's production tee, likely due to both erosion and corrosion as internal wall of the tee has already been coated with a thin, black films. Hence, utilization of the well despite its condition is not anymore economical and safe.

3.2 Acid Inflow in Palinpinon-1

Well B1 was the first Balasbalas well drilled in year 1990. Post drilling testing showed a neutral pH ranging from 5.5 to 6.6 with water chemistry consistent with the usual concentration of high temperature neutral-pH chloride waters in SNGF. With the commissioning of the plant in 1995, the well was tested again and unexpectedly, pH was lower. Its chemistry showed interplay of two dominant feed zones: neutral pH and low pH (Figure 5). This is also supported by other water parameters where low pH fluids correspond to high SO_4^{2-} and Mg^{2+}. After a year, reservoir SO_4^{2-} reached a maximum concentration of ~600ppm and corresponding pH breached the 4.0 limit. This implies dominance of shallower acidic fluids (Vidal, 1998).

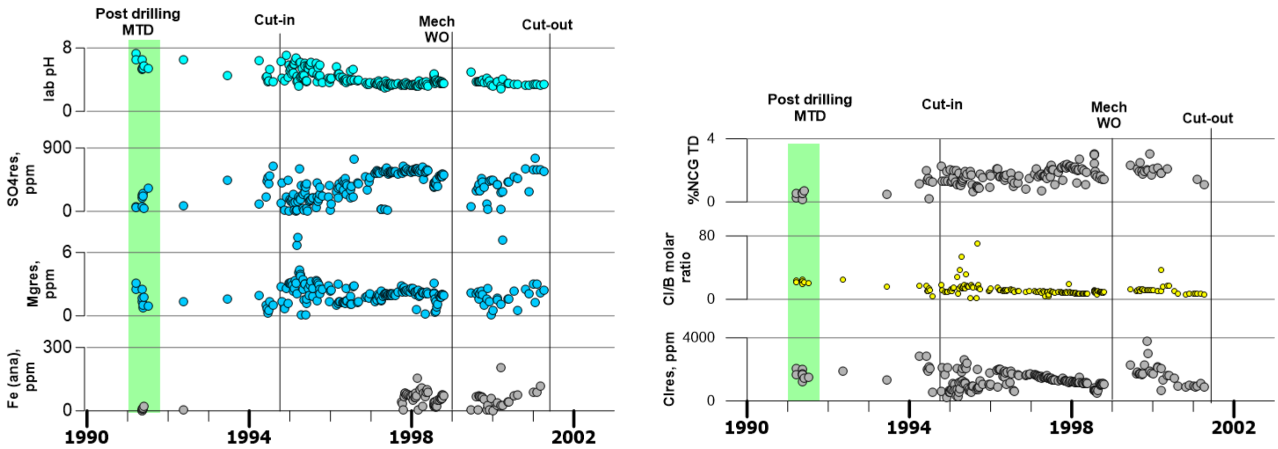

Figure 5: Well B1 selected geochemical parameters.

At the surface, the corrosion and erosion problem was felt due to the high thinning rate, elevated total suspended solids (TSS) and total Iron (Fe) concentrations. Casing Inspection Caliper (CIC) survey was then conducted in 1997 to evaluate the casing integrity and the results identified a thinned section in the production casing. A mechanical workover was then conducted in 1998 to clear up the blockage, thus improving well output and allowing the recovery of the contribution from the deeper neutral-pH feed zone, and to reline the thinned section. However, the objective was not completely met due to unexpected downhole conditions. The top of liner (TOL) was tagged at 44 meters lower than its setting depth, resulting in a 15m gap (or an open hole) from the production casing shoe. This depth was the source of high TSS (from formation) and the high Fe from the corrosion of this section (Aqui et al., 1999). The workover did manage to clear a part of the open section, although relining was aborted. Fresh water injection and adoption of sweep bend in the wellhead assembly was employed to mitigate the detrimental effect brought by the corrosive and erosive nature of B1 fluid. Given this situation along with consideration in risks and cost, the well was eventually shut and was replaced by a new Balasbalas well. By 2008 when steam supply was marginal, B1 relining was pursued. The well was utilized as its discharging fluid turned dry or nil water flow. Continued utilization of the well did not show any indication of acid inflow.

Another well, J6, showed similar behavior with B1 (Figure 6). Baseline discharge exhibited a neutral pH. However, acid inflow was observed after six years. Its pH decreased from 5.6 to 5.8 to 2.9 to 3.7 with a corresponding increase in reservoir SO_4^{2-} and Mg^{2+}. Based on evaluation by Bayon (1994), the appearance of low pH waters was triggered by the formation of anhydrite blockage during earlier discharge testing. The blockage has isolated the contribution from the deeper neutral fluids. Testing at throttled condition shows lower pH compared to fully open condition. Based on the depth of anhydrite blockage, the likely entry of acid fluids is at the shallow feed zones. This was supported with the result of downhole sampling. The well was shut until 2004.

Prior to this year, there has been observed expansion of the two-phase condition at shallow levels of the reservoir after more than two decades of field exploitation (Malate et al., 2010). This prompted to revisit the previously cannot-be-used (CBU) wells: those that turned non-commercial due to cooling effects of reinjection breakthrough (in Palinpinon-1) and wells with acidic discharge including J6. Upon testing, the discharge characteristic turned highly two-phase from a baseline of liquid enthalpy as shown by excess discharge enthalpy in Figure 6. Initial pH was 3.91 then increased to 4.5 - 5.0. Neutral-pH indicators exhibit an increasing trend while a reverse trend was seen for acid parameters. With this development, well J6 was recommended for cut-in and was able to augment steam supply of Nasuji power plant.

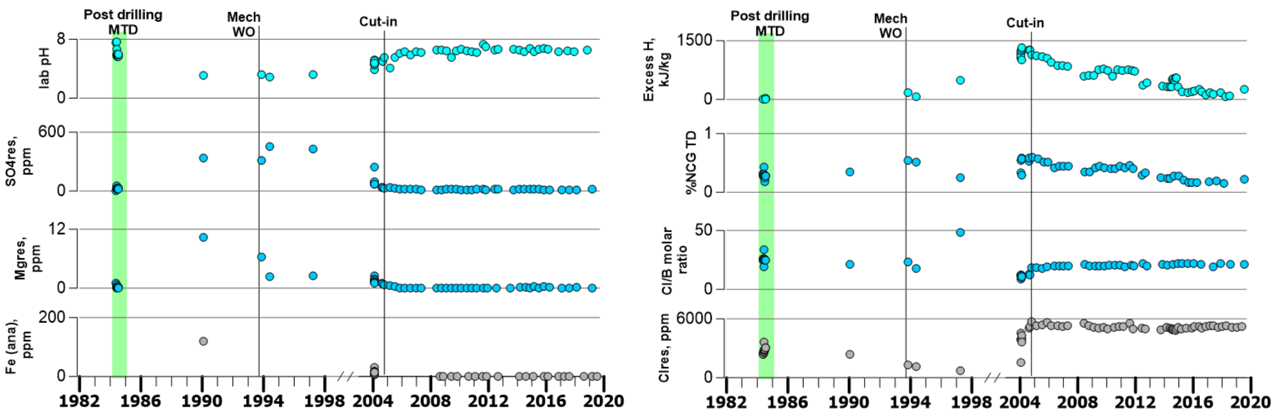

Figure 6: Well J6 selected geochemical parameters.

4. POSTULATES ON THE ORIGIN OF ACID FLUIDS

Using a ternary plot of major anions (Cl-HCO_3-SO_4), the representative acidic chemistry can be classified as a mixture of Cl and SO_4 waters with fluid pH range of 2.98 to 4.57. Generally, chloride, sulfate, and non-condensable gases at total discharge (NCG TD) content of the fluids ranges from 629 to 2487 ppm, 292 to 1394 ppm and 0.25 to 1.75%, respectively. Using ternary plot for inert gases (N_2-Ar-He), the available data shows no magmatic origin. It is to be noted however that there is only limited data for inert gases since laboratory analysis of residual gases started only in the 1990s.

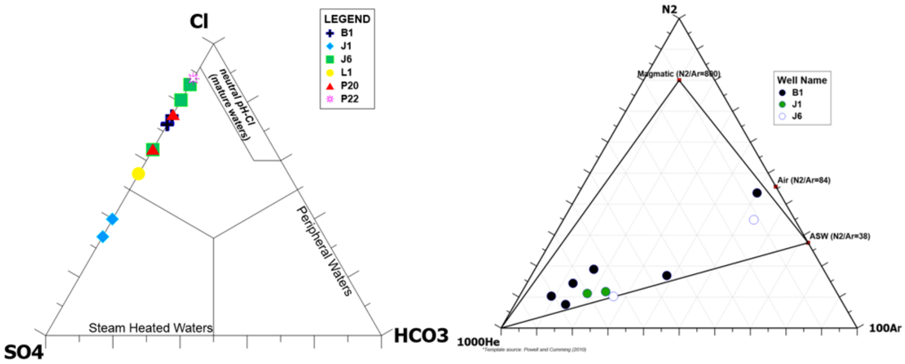

Figure 7: Ternary plot of Major anions (left) and Inert gases (right).

Initially, there were three proposed mechanisms to explain the observed acidity in Palinpinon as provided by Candelaria (1992, p. 6):

(1) Sulfur (S) hydrolysis,

(2) Contact of deep aquifer fluids with acid magmatic volatiles, and

(3) Pressure drawdown brought about by massive field exploitation induced inflow of acidic fluids from the shallow steam condensate zone to much deeper levels.

The third mechanism is most plausible to explain the experience in Palinpinon. D'Amore et al. (1993) suggested that a gas-rich steam condensate layer is forming at shallower depths as a consequence of pressure drawdown. The steam condenses into ground waters, and H2S is oxidized in the vadose zone to sulfate, forming acid sulfate, steam-heated waters. This explains the high SO_4^{2-} signature of acidic waters coupled with a decrease in Cl^- concentration. Stable isotope (Gerardo, 1993) was able to establish the ^{18}O and reservoir Cl concentration of the acid waters that dilute the neutral-pH geothermal brine. The presence of tritium in production wells further confirms the incursion of shallow ground water as compared to nil concentration for other wells. A cold gas manifestation or Kaipohan is present at the southern part of the production field with elevation greater than 1100 mASL. This area is marked by acid altered ground and was suspected to be the "source," acting as shallow acid aquifer that migrates to the production sector as an effect of the pressure drawdown. Illustrated in Figure 8 is the likely path assuming the acid sulfate water travels through the permeable structures from Kaipohan area to the production sector.

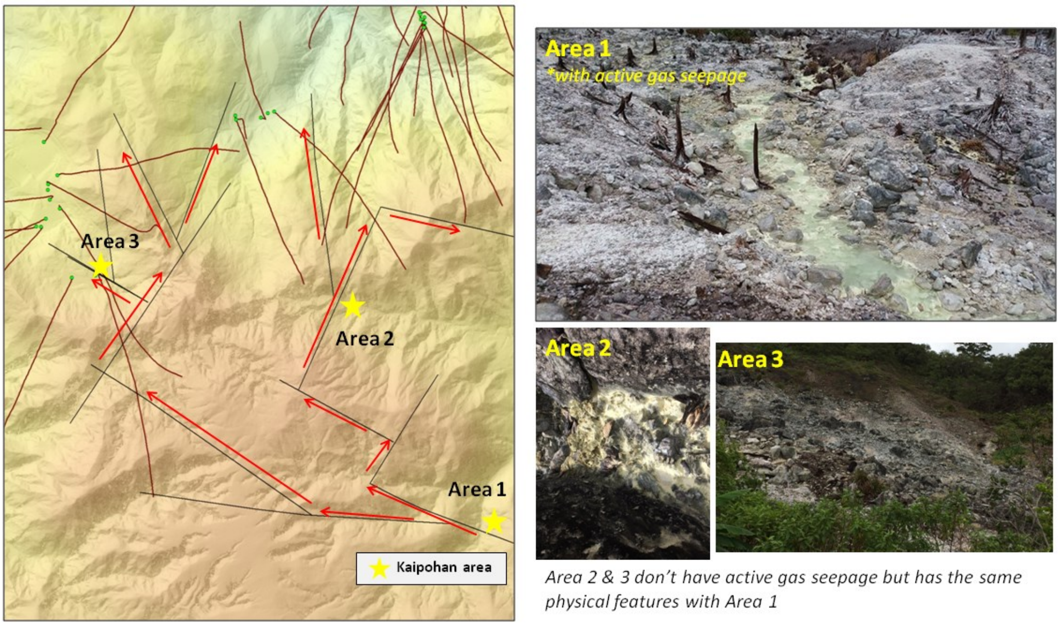

Figure 8: Proposed path (left) Kaipohan pictures (right).

5. IMPLICATIONS ON STEAM AUGMENTATION

With the experience in the 1980-1990s for the wells drilled closer to the upflow zone, the area was originally not favored due to the risk of encountering acidic fluids. Fortunately, returning injection fluids was able to successfully suppress the shallow acidic inflows as they serve as artificial pressure support that significantly reduced rate of pressure drawdown in the field. With the neutralization of former acidic wells, the area was revisited and drilling of new wells within the area was pursued. To date, a total of four wells were drilled (as represented by thick black lines in Figure 2). Three of these were discharging two-phase neutral fluids while the other well turned dry during its post drilling discharge testing, indicating that the water level in the area is lower compared to its total depth. A total of ~37MWe was realized from these wells (B4, L5, L6 and L7) which were drilled from 2010 to 2017.

6. CONCLUSION

Acidic inflows observed in production wells are regarded as disadvantageous, as this renders said wells to be unproductive and unusable. However, in the experience of the Palinpinon Geothermal Production Field, the dynamic reservoir processes coupled with continuous field exploitation brought about favorable changes in the geochemistry of these acidic wells: the production wells to dry up, eliminating the acid feed and incursion of reinjected fluids suppressed the source of acidity in some of the two-phase wells. Through further testing, some wells were proven to be commercially viable for production and were cut-in to the system to increase steam production. Due to this experience, drilling targets for steam augmentation could now be pursued in areas previously avoided due to the presence of acid inflows. Moreover, in the case of SNGF, wells drilled toward the postulated upflow area produced high output two-phase neutral fluids or dry discharge. Adherence to preferred reinjection loading and proper well utilization must continue to ensure the management of the acid feed zone.

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