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Silica Inhibitor Application during Medium-Term Discharge Tests of Geothermal Wells: The BacMan Geothermal Field Experience

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ABSTRACT

Discharge testing of newly-drilled wells, particularly in exploratory or expansion areas is an important activity in any geothermal development. The data obtained in such activity is essential in resource evaluation that will determine the level of development and production. During the test, the wells are discharged to silencers where the brine is separated at atmospheric pressure and temperature. In such condition, silica supersaturates and causes deposition problems along the discharge lines and in the injection well. Such situation hampers the completion of the tests and damages the injection well. The usual practice to mechanically clean the clogged lines and work-over/acidize the injection well are tedious, time-consuming, and very costly.

The use of silica inhibitor during discharge testing is an alternative method that could ensure completion of the tests in a timely and less-costly manner. Such method was applied and proven effective at the Bacman geothermal field, Tanawon sector. A phosphino-carboxylic acid copolymer inhibitor was used to treat the brine at 8 ppm dosage. Results showed that silica deposition rate was reduced from 0.22 mm/day (untreated/diluted) to 0.04 mm/day. This prolonged the effective capacity of the discharge lines and injection well and resulted to the completion of the test in a timely and cost-effective manner.

1. BACKGROUND

The Tanawon (TW) sector is one of the three main expansion areas of the 130-MW Bacon-Manito Geothermal Business Unit (BGBU). It is located at the southern part of the field (Figure 1) and currently has three production wells (TW1D, TW2D, and TW4D) and one reinjection well (TW1RD). Since it is a new expansion area, it's long-term sustainability and estimated field capacity needs to be evaluated. Hence the wells have to be discharged individually and simultaneously for a reasonable period of time. During the test, the wells are discharged at atmospheric condition thru silencers and the separated brine is disposed via a cold reinjection system consisting of catchments and alvenius lines to TW1RD at the injection pad.

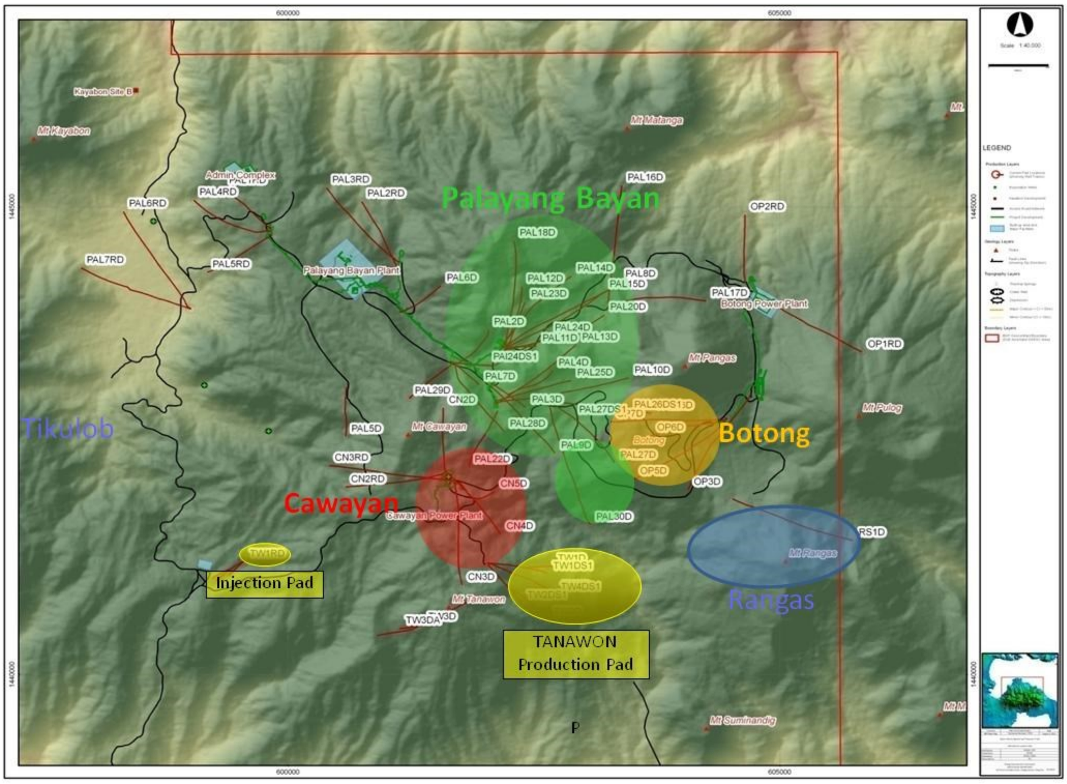

Figure 1: Well location map of the Bacman Geothermal Field, Tanawon Sector

In geothermal systems, heat extraction is maximized based on the fluid's silica scaling potential (Gunnarson & Arnorsson, 2003). Deposition is highly dependent on the silica concentration, pH levels, temperature, flow rates, aeration and ions in the solution (Brown, 2011). The primary measure of scaling tendencies is thru the silica saturation index (SSI) which is a ratio of the fluid's silica concentration and the equilibrium concentration (a function of temperature). The silica equilibrium concentrations at high temperatures and pressure are calculated (Fournier & Rowe, 1977). As the temperature drops, the solubility of silica in solution also decreases and effectively yields higher saturation indices. An SSI of greater than 1.0 means that thermodynamically, silica deposition is expected to occur along the system. The kinetics of this precipitation is a different aspect but is usually characterized by the fluid flow rates and induction period. Since during exploration discharge tests the fluids are usually separated at atmospheric condition, silica supersaturation is inevitable.

The Tanawon discharging wells have relatively high silica concentrations (Table 1) while the cold reinjection system (atmospheric flashing) yields very low operating temperature. This combination of chemistry and process promotes silica supersaturation, and scaling is expected to occur within the duration of the discharge test. Hence during the discharge tests, silica deposition must be mitigated to ensure sustained acceptance of reinjection wells as well as prevent clogging of the injection lines.

Table 1. Tanawon wells sample discharge flow rates and water chemistry (as analyzed)

	TW1D	TW4D
Total mass flow (kg/s)	77	50
Ave. weir flow (kg/s)	49	20
Opening	Full bore	Throttled
Estimated Temperature (°C)	90	88
Silica (mg/kg)	753	694
Chloride (mg/kg)	8218	7700
pH	8.5	8
SSI	2.42	2.28

2. TANAWON DISCHARGE SET-UP AND EARLY SCALING MITIGATION

The simultaneous discharge of wells TW1D and TW4D commenced on July 24, 2012. The schematic diagram of the discharge set-up and inhibitor introduction is shown in Figure 2. A silica inhibitor, Geogard SX (GSX) dosing was later introduced at the catchment.

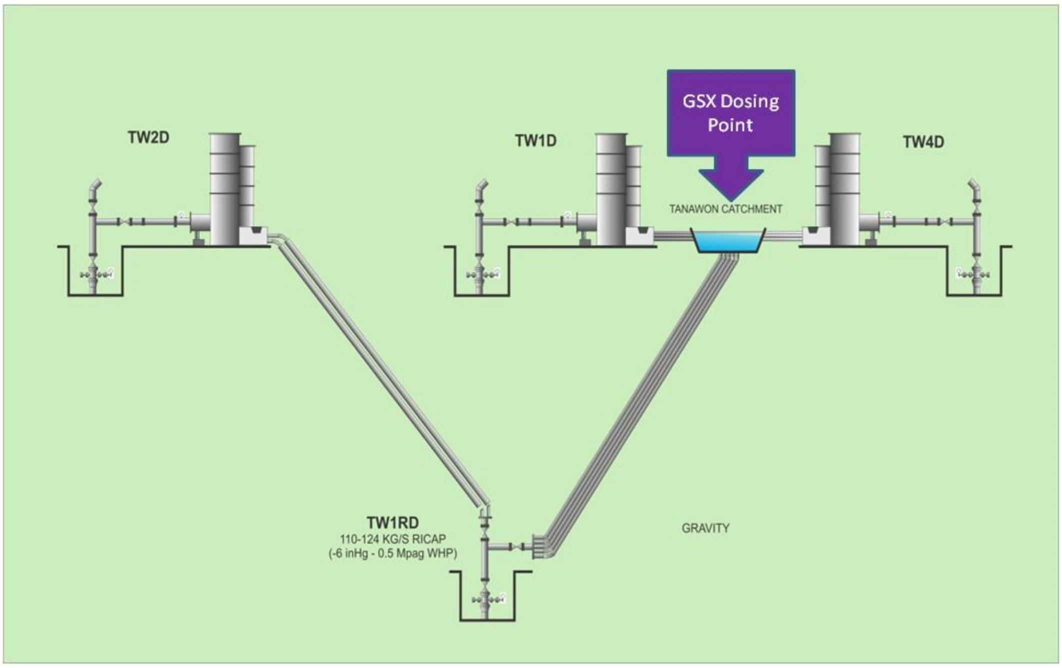

Figure 2: Tanawon Simultaneous Discharge Test set-up (not drawn to scale).

These two wells discharge to individual silencers, but the brine from the weir boxes is mixed immediately at the catchment. The mixed brine goes through six alvenius pipe lines while well TW2D has separate lines directly connected to the reinjection well. At the onset of the discharge, fresh water dilution was utilized as initial silica scaling mitigation measure. This aims to dilute and decrease the silica concentration by adding 20-30 kg/s of fresh water to the brine in the Tanawon catchment basin. However, it was a balancing act with temperature as the fresh water also reduces the operating temperature of the brine and decrease silica solubility. Furthermore the volume of the diluting water eats up on the limited capacity of the injection well. Silica deposits were later found present near the wellhead of TW1RD indicating the inefficiency of the process to control silica scaling (Alvarado & See, 2013). Subsequently the injection capacity of TW1RD declined significantly.

The application of a silica inhibitor GSX was considered in the test to save TW1RD from any further decline in injection capacity. GSX is an anti-scalant inhibitor that has been experimented and commercially applied before in the then Botong Fluid Collection and Recycling System (FCRS). Botong was one of the sectors in the BacMan field. The phospino carboxylic acid copolymer GSX was then used to treat the Botong fluids with extremely high silica concentrations of 1000-1300ppm (Baltazar, et al., 1998). The inhibitor was injected at the separator vessel earlobe just after separation of steam and brine. The GSX was proven effective with inhibition efficiencies of 38.1%-95.7% (Baltazar, et al., 1998) and was also implemented in the Malitbog sector in Leyte Geothermal field in 2003 (Alcober, Candelaria, Mejorada, & Cabel, 2005).

The Tanawon testing was completely different from that of the Botong sector in terms of SSI and physical set-up, but the Tanawon brine chemistry was evaluated and the inhibitor's characteristics were reviewed. Thus, the GSX injection replaced the freshwater dilution in November 2012 with an original dose of 2 ppm. The GSX was injected at the Tanawon catchment at atmospheric pressure using a dosing pump. An opportunity to inspect and document the alvenius lines came about in February 2013 and at this dosing concentration, scaling was visibly reduced but was still present. The GSX dose was recalculated and increased to 8 ppm starting February 2013 until the termination of the discharge testing in June 2013. Chemistry of the fluids was also monitored as samples were taken at the weir box and at the two-phase lines using a Webre separator.

3. INSPECTION AND DOCUMENTATION

Two major inspections were conducted, one was in February 2013 during the replacement of the alvenius lines and the second was in June 2013 upon the termination of the Tanawon Simultaneous Discharge Test (SDT).

3.1 February Inspection

The first full inspection of the Tanawon reinjection lines since the beginning of the simultaneous testing was done in February. This period covers both the water dilution method and the initial 2ppm GSX dosing. The two methods are differentiated by the installation of a redundant line where freshwater-diluted and dosed brine would have passed through.

Significant depositions were discovered at the reinjection lines of thickness 25-40mm at the original lines, as shown in Figure 3. The depositions were adherent and very hard scales, and had multi-layers of vitreous compact scales and powdery grain-like scales.

Figure 3: Depositions at the first TW line inspection lines

In addition, deposits were also found at joint connections (valves and elbows) where there is a shift in the flow velocity and flow direction. One of the valves was actually completely blocked (Figure 4). Deposition characteristics were similar to those previously described.

Figure 4: Massive depositions at joints, elbows, and valves

The initially dosed redundant brine was also inspected and shown in Figure 5. The scale patterns were uniform with thickness 2-15mm.

Figure 5: Redundant line used for the dosed brine fluid

Petrological analyses confirm the scales collected from these lines are amorphous silica as summarized in Table 2 (Ramos, 2013).

Table 2. Petrologic analysis findings

Sample	Description
TW RI line	Amorphous silica (100%)
TW RI line elbow	Amorphous silica (~99%) Impurities (silt-sized calcite, amorphous clays)
TW RI redundant line	Amorphous silica (~98%) Impurities (silt-sized calcite/feldspar crystals)

3.2 June Inspection

Re-inspection after almost four months with an increased GSX dosing did not fully eliminate the scaling in the alvenius lines. However, much improvement has been observed as the thickness of the scales in the lines was reduced to only 4-5mm. The scales were dark gray, uniform and still very adherent (Figure 6).

Figure 6: Inspected alvenius lines after increased GSX dosing to 8ppm

A more thorough line inspection (catchment to TW1RD) was also conducted to find deposition profiles. This however was not conducted in the previous inspections. It was found out that right at the downstream pipe line of the catchment, the scales were found similar to Figure 6 with thickness of 3-5mm only, while right prior the injection to TW1RD, the scale was measured to be 6mm.

4. INHIBITION EFFICIENCY

There is indeed an apparent improvement in the scaling rates at the 8ppm injection strategy as adapted from the Botong FCRS set-up. Figure 7 shows a comparison of scales collected at the two GSX dosing rates while Table 3 summarizes the three silica mitigation methods and their calculated deposition rates using average thickness measured.

Figure 7: Scale samples collected in June 2013 (leftmost) and February 2013 (middle)

Table 3. Comparative scaling properties

	High GSX dose 8ppm	Initial GSX dose 2ppm	Freshwater Dilution Undosed
	Feb 2013- June 2013	Nov 2012- Feb 2013	July 2012- Nov 2012
No, of days	116	95	136
Thickness, mm	5.0	13.0	30
Scaling rate mm/day	**0.04**	**0.14**	**0.22**

These values validate the positive effects of the inhibitor GSX even in the cold reinjection set-up of the Tanawon wells. However, optimum dosing rates must be identified to maximize the inhibition effects as is the case of the 2 ppm and the 8 ppm dosing. Taking the baseline as that of the undosed and freshwater diluted, the deposition rates were reduced by as much as 82% at dosing concentration of 8.0 ppm.

5. CONCLUSIONS AND RECOMMENDATIONS

Visual inspection and deposition rate calculations showed the effectiveness of Geogard SX (GSX) in silica inhibition at low-temperature injection scheme. The 82% reduction in deposition rates translates to less probability of work over and acidizing in the reinjection wells, and ensured continuous well discharge and completion of the test.

Optimization of dosing rates was pronounced in the study conducted. The low dosage 2 ppm was able to reduce the deposition rate compared with freshwater dilution, while the optimum dose of 8 ppm was able to reduce the scaling much further. The accumulation of scales in the weirbox and catchment basin could be the result of the inhibitor not being fully mixed in the brine at this location; in the box-type geometry of the weirbox and the catch basin, the corners and surfaces of the fluid may not be reached by the mixing space of the inhibitor. This could be resolved by injecting the inhibitor further upstream (in the two-phase line) as is the case in the hot reinjection set-up of Botong FCRS.

Overall, the silica inhibition technology is a practical mitigation measure in future wells for discharge tests and could be revived in the operational Bacman FCRS set-up. Actual dosing optimization with respect to the fluid's chemistry must be performed in every discharge test. Regular and scheduled inspection and documentation is recommended to check and balance the performance of the inhibitor.

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