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Testing of New Silica Inhibitor in the Botong Reinjection System, Bacon-Manito Geothermal Production Field, Philippines

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ABSTRACT

A polyacrylic copolymer-based silica inhibitor (F3680), was tested in the Botong Reinjection System (BRS) of the Bacon-Manito Geothermal Production Field (BGPF) using the brine separated at 0.70 MPa with about 45% oversaturation with respect to amorphous silica. The test was aimed to determine the inhibition property and applicability of F3680 and as an alternative silica inhibitor chemical for GSX at the current cold injection set-up and the proposed hot injection scheme. The chemical was dosed at an effective concentration of A ppm at the two-phase fluid tapped from the header of the production wells before the main separator vessel.

Treating the brine with F3680 at the cold injection set-up achieved an inhibition efficiency of 55.8% or an average deposition rate of 1.76 mm/day as compared with 3.98 mm/day of the untreated line. The new chemical reduces silica deposition and produced layered and less adherent to surface type of deposits, to granular and soft gel-type form.

In the hot injection scheme, yellowish slurry type of deposits is produced along the hot line and in the retention vessel. The deposition rate is measured based on weight difference method since the type of deposits are loose and non-adherent to the pipes. Minimal deposits are formed along the pipes with highest deposition rate of 0.15 g/day measured in the inspection spools.

Based on the nature of deposits formed, F3680 is a promising silica inhibitor that can replace the existing chemical inhibitor.

1. INTRODUCTION

The Fluid Collection and Reinjection System (FCRS) in the Botong Sector of the Bacon-Manito Geothermal Production Field (BGPF) was commissioned in March 1998, supplying steam for the 20MW modular power plant. Since commissioning, Geogard SX (GSX) has been used as the silica inhibitor. Presently, the brine is being disposed of through a low-temperature injection system and GSX is injected at the ear-lug of the separator vessel, (the hot portion of the FCRS), before the brine is totally flashed to the atmosphere (the low-temperature portion of the brine disposal system). The separated brine is then collected in a baffled thermal pond, dropping its temperature further to allow direct deposition of monomer silica and formation of colloidal silica to precipitate and settle in the pond prior to injection to well OP-2RD.

A hot injection scheme is being proposed for implementation as a replacement for the existing cold injection system. GSX has already been pilot-tested for the hot injection scheme, with better results than that of the low temperature brine disposal scheme.

Formula 3680 (F3680), a polyacrylic acid copolymer-base chemical was tested in Botong brine to determine its silica inhibition property, applicability in both cold and hot injection system and as an alternative silica inhibitor chemical for GSX. Currently, GSX is being dosed to the system at an effective concentration of A ppm. Testing of F3680 at the same effective concentration was conducted using both the cold and hot injection at the pilot test facility (PTF). The tests mimic and simulate the existing cold injection scheme and the design of the hot injection system.

2. SILICA SCALE INHIBITORS

Chemical scale inhibitors under certain conditions can be used to delay, reduce, or even eliminate scale deposition. The silica inhibitors function as: 1) dispersants; 2) anti-precipitants; 3) sequesterants; 4) chelating agents; 5) crystal modifiers or 6) sludge conditioners to name a few and is dependent on the mechanism of silica deposition (Cowan, et al.,1976). Other effects of using organic scale inhibitors were prolonging the induction period (time before precipitation), decreasing rate of precipitation, reducing the final quantity of the precipitates and highly distorting the silica crystals.

Geogard SX, a phosphino carboxylic acid co-polymer, functions as dispersant to control colloidal silica deposition and as sequestrant of hydrated oxide (rust) to prevent monomeric silica deposition (Garcia, et al., 2000). The mechanism in inhibiting silica deposits of the new chemical inhibitor, F3680, is through threshold and lattice distortion as well as by dispersion (Nicolas, pers. comm., 2007). Chemical inhibitors, which are polyacrylate derivatives, not only function as dispersants and sequestering agents but also act as a deflocculant. The polymer appears to form a thin, self-strippable layer on the surface and thus preventing hard silica deposits to form on the surface of the pipe that are hard to clean.

3. PILOT TEST FACILITY

Figures 1 and 2 show the schematic diagrams of the cold and hot injection system PTF set-up, respectively. Figure 1 mimics the actual cold section of the reinjection system in Botong except for the location of the dosing point while Figure 2 was designed to proportionally scale down the pipe sizes and brine flows to attain similar fluid regime in the proposed hot injection line that will be constructed, i.e. fluid velocity and travel time of the fluid in the pipe. Both test set-ups is composed of the following parts namely: the dosing system, the mini-separator, the pipeline, the mini-silencer, the inspection spools, the sampling points with cooling coils, thermo wells and pressure indicators, and the retention vessel.

The set-up was tapped from the two-phase line header; the confluence of all production wells in Botong, using a 1-inch line. The dosing pump for the chemical inhibitor was installed before the mini-separator to ensure complete treatment of the brine and avoid silica deposition in the pipeline. Brine separation was duplicated using a mini-separator vessel while thermowell and pressure gauges were installed after the mini-separator for brine temperature and pressure monitoring.

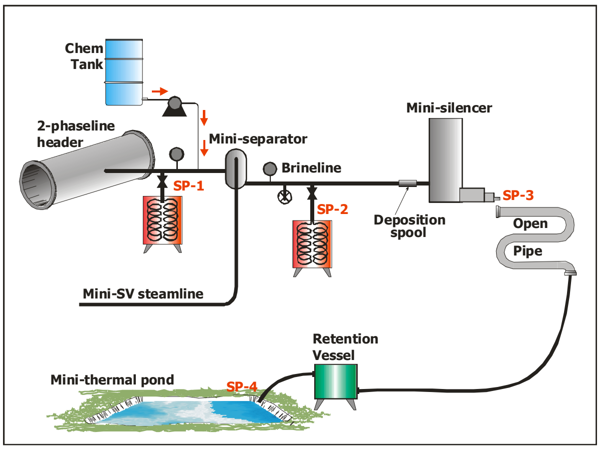

Figure 1: Cold Injection Test Set-up

In the cold injection system PTF, a deposition pipe, which is a 6-inch ϕ open pipe with three lanes, allows enough residence time for the brine coming out from the mini-silencer to polymerize and deposit. It was used to simulate the thermal pond, where the brine is cooled and allow depositing the silica. Deposition rate was calculated using the average thickness of the deposits formed at different brine temperature represented in the different lanes of the open pipe.

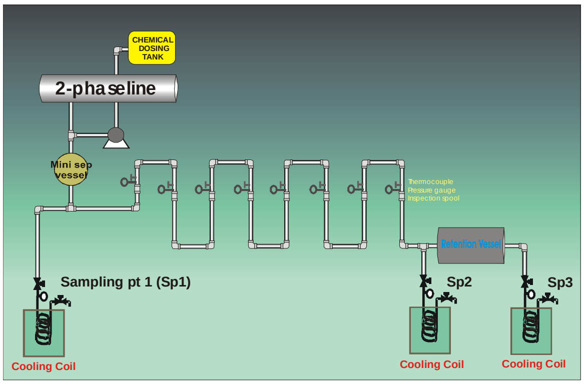

Figure 2: Hot Injection Test Set-up

On the other hand, several inspection spools were installed along strategic locations throughout the length of the half-inch diameter pipeline in the hot injection system PTF. The locations of the inspection spools are designed to simulate the brine line condition and provide a segment where the silica deposition rate can be calculated and compared. The retention vessel, considered an integral part of the test pipeline configuration, was used to further delay the travel time of the brine, simulating the 1.5 km actual distance from the separator to the reinjection well.

The entire closed system was insulated to minimize heat loss and maintain an isothermal temperature. A thermowell and pressure gauges were installed after the mini-separator for brine temperature and pressure monitoring.

4. METHODOLOGY

The flow rate, temperature and pressure were measured daily during the entire duration of the testing. Samples were also collected from the different sampling points (SP1, SP2 & SP3) daily and analyzed for chloride and total silica.

All inspection spools were weighed before and after the test to determine deposition rates. Samples from the retention vessel were collected and air-dried before submitting for microscopical analysis using Scanning Electron Microscopy (SEM) imaging and Energy Dispersive X-ray Spectrophotometry (EDX).

5. RESULTS AND DISCUSSION

5.1 Cold Injection Testing

5.1.1 Scale Characteristics

The deposits formed at the open pipe using A ppm F3680 are layers of brownish and moderately hard deposits at lane 1 to flaky and brittle upon drying. At lane 2, granular and compact form of deposits was observed while soft and porous type of deposits was observed at lane 3. (Figure 3) Generally, the deposits are poorly formed, have lesser tendency to adhere and can be easily removed. This is the inhibition mechanism of polyacrylic acid based scale inhibitors where the polymer forms a thin monomolecular layer on the surface. This consequently reduced the tendency for the scale to adhere and thus prevents scale deposition. Layers of monomolecular silica are formed upstream of the pipe which further change to colloidal deposition upon continued binding of the monomers with the adjacent monomeric particles as the brine flows along the pipe. These colloidal particles are generally hydrated and porous in nature.

Another characteristic of F3680 is its ability to cause considerable crystal distortion once crystallization takes place. This distortion prevents dense and uniform deposit as crystal growth occurs.

Figure 3: Characteristics of deposits at the open pipe using A ppm F3680 a) layers of thin but moderately hard; b) granular and compact; c) very soft and porous

5.1.2 Deposition Rates

The change in form and structure of deposits can be correlated with the decline in brine temperature along the open pipe. Table 1 shows the range of temperature along each lane of the pipe and the corresponding silica deposition rates.

Figure 4 shows the relationship of deposition rates with the amount of monomeric silica in the solution. Based on the figure, silica was deposited from supersaturated brine solution with a silica saturation index (SSI) as high as 1.4 at a rate that increases with the amount of monomeric silica in solution. Although blank run and F3680 treated line showed similar trend, deposition rates of F3680 treated line was significantly lesser than that of the untreated line. The linear relation between deposition rate and % monomer is apparent only at blank run; this is due to the absence of chemical scale inhibitor that will hold the silica in solution and slows down the deposition. Treating the line with A ppm F3680 reduces the deposition rate at least about 40%. This is typical of threshold mechanism where the weight ratio of threshold active compound to scale-forming component is 100:1. Since the separated brine in Botong contains about 1000-ppm silica, the brine needs about A ppm of the chemical inhibitor to hold the silica in solution.

Table 1. Deposition Rate With and Without Inhibitor.

Location	Brine Temp (°C)	Blank (mm/day)	10 ppm (mm/day)
Lane 1	60-83	8.17	2.53
Lane 2	45-60	4.45	1.53
Lane 3	35-45	3.50	0.55

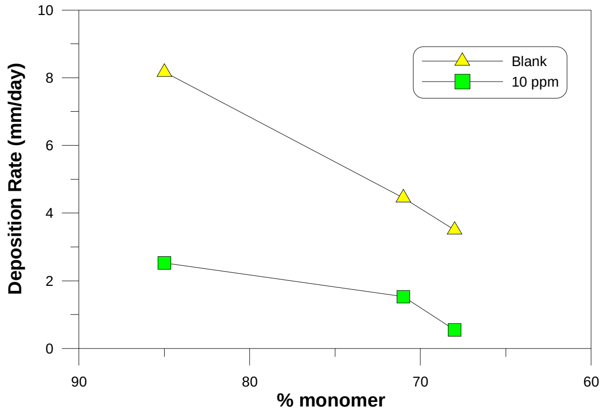

Figure 4: Deposition rates vs. % monomer

It is observed from the deposits formed along the open pipe that precipitation occurs much more slowly from the solution when the aqueous silica is in the form of polymers rather than as monomers, as evidenced by the decline in thickness of the deposits. Accumulated deposit thickness at the pipe declined from lane 1 to lane 3. This implies that the deposits formed immediately after flashing from the mini-silencer is in monomeric form. Lane 1 has the highest tendency to form solid and moderately hard scale (not gel type) because it has the highest percent of monomeric silica in solution. Ageing the brine by allowing it to pass lanes 2 and 3 of the open pipe allows the silica to be converted to polymerize form, which is weakly flocculated, and gel-type. Since much of the silica has deposited upstream (lane 1) and the brine downstream is already silica depleted, deposition rates will consequently decline in lanes 2 & 3.

5.2 Hot Injection Testing

5.2.1 Scale Characteristics

Yellow slurry-type of samples was collected from the retention vessel after 27-day testing was completed. The type of deposits collected from the vessel is non-adhesive to the pipe wall that can be easily flushed out with pressurized water. Figure 5 shows the picture of the deposits immediately after opening the vessel. The elemental composition of the sample taken from the collected slurry in the retention vessel based on EDX analysis are composed mainly of As (~50%), S (~20%), Si (~10%), and O (~20%) with trace amounts of Ca and Sb.

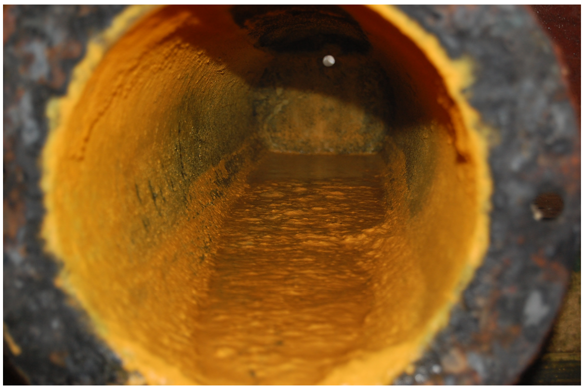

Figure 5: Photo of the retention vessel with the slurry deposits after the testing

5.2.2 Deposition Rates

The rate of deposition along the test pipeline ranged from 5 to 150 mg/day (Figure 6). Based on the results, the highest deposition rate of 150 mg/day was measured at the spools installed between 244-250 m away from the mini-separator. The deposits are highest in this area probably due to the flow regime of the brine along the pipelines. Based on the layout of the pipes, there are more bends in this section, probably causing higher system pressure loss leading to scale deposition (see discussion below). As expected, the lowest deposition rates with very thin deposits were found at the hottest portion of the PTF closest to the mini-separator (first 175m). The deposition rates here ranged between 5-30 mg/day at temperatures between 120°C- 160°C.

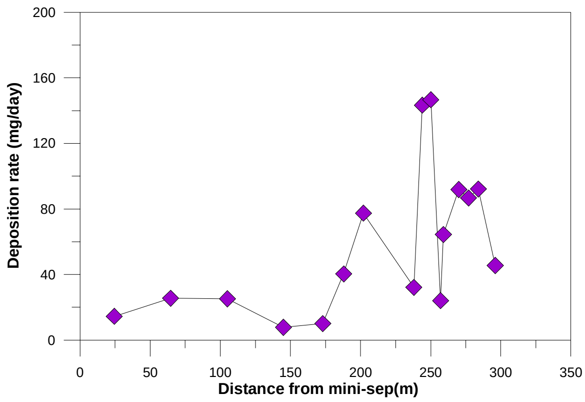

Figure 6: Deposition rates along the pipelines

Figure 7 shows the pressure and temperature profile of brine along the pipeline. During the test, the temperature and pressure were not maintained contrary to design. This is attributed to the piping configuration of the PTF. The temperature drop was minimized (from 160°C to 120°C) for the first 175m from the mini-separator vessel. After this, line temperatures further dropped from 110°C to its lowest of 70°C beyond 200m distance from the mini-separator. Based on the line temperature profile alone, it was expected that deposition rates would be highest beyond 200 meters, since deposition rates increase as fluid temperature drops following the amorphous silica solubility (Iler, 1979).

Line pressures generally follow the temperature trend. The highest drop in pressure (6 MPaa) was noted at the same area were the deposition rate was highest. This section corresponds to the span with the highest temperature drop, since the brine velocity decreased due to the decline in flowrate as an effect of increased number of bends in the pipe layout. This portion of the PTF (120°C) mimics the worst condition within the hot reinjection line, where brine is subjected to further flashing due to pressure drop with a corresponding temperature drop of 45°C from the separation temperature of 165°C. The measured deposition rate at this portion is 150 mg/day or 55 g/yr. Deposition rate was measured by weight method unlike previous silica inhibition testing that used thickness of deposits, as basis for the deposition rate measurement due to the fact that the deposits formed during this test was soft and non-adherent to the pipe. Minimal coating of deposits was present along the pipelines.

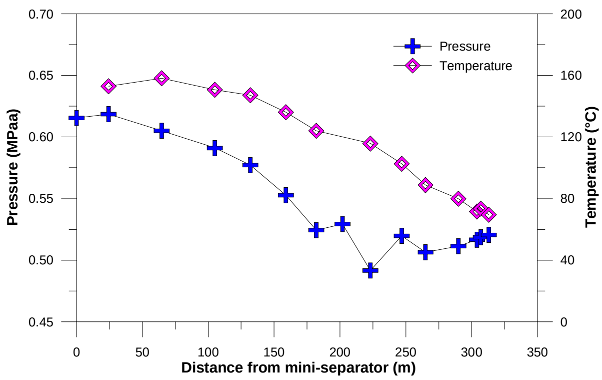

Figure 7: Pressure and Temperature profile along the pipelines

6. SILICA AND CHLORIDE

The silica concentrations at the different sampling points in the cold injection set-up showed erratic results indicating that the brine is not homogeneous and that polymerization has occurred at different molecular weights/lengths. Consequently, samples containing longer chains will give higher concentration. However, the decline in total silica at the end of the set-up is apparent (Figure 8). The drop in total silica up to the end of the set-up is >200 ppm which translates to the amount of silica that deposited along the line.

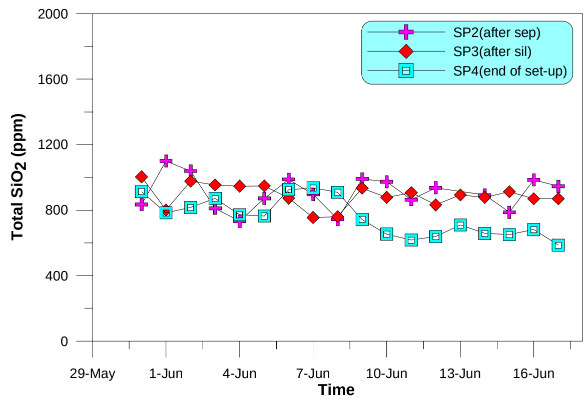

Figure 8: Profile of Total Silica in Cold Injection Set-up

Chloride concentrations at the different sampling points showed more stable results except for the 10-ppm F3680 concentration. The deviations are due to fluctuating brine flow rate.

On the other hand, approximately 100-mg/L drop in total silica was measured along the whole length of the hot injection test pipes. Similar with the cold injection testing, the fluctuation in the silica concentrations during the duration of the testing indicates that the brine is not homogeneous which is also consistent with the Cl concentration trend (Figure 9). The variation in silica concentrations is due to the fluctuations in the temperature causing polymerization of silica to occur at different molecular weights/lengths. The brine homogeneity is hard to maintain because of the fluctuating brine flow at the source and low brine flowrate flowing in the pipe (~0.039 kg/s).

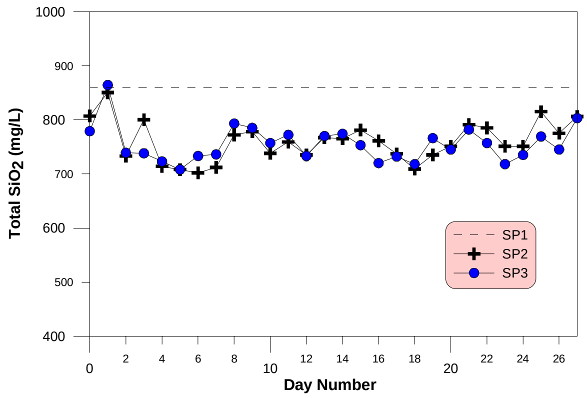

Figure 9: Profile of Total Silica in Hot Injection Set-up

7. SUMMARY AND CONCLUSION

- F3680 is effective in controlling silica scale formation in both the cold and hot injection scheme in Botong.
- Average deposition rates using A ppm F3680 in cold injection testing is 1.76 mm/day as compared to untreated line, which is 3.98 mm/day.
- Deposition rates are highest immediately after the brine flashed from the mini-silencer where monomeric silica is highest at this portion of the pipe. Rate of deposition consequently declines as the brine cools downstream.
- Brine treated with F3680 produced poorly formed, layered, thin but moderately hard silica deposits, to granular and compact and finally soft gel type that can be easily removed.
- Deposition rates in hot injection testing were as low as less that 30 mg/day (11 g/year) at the hotter portion of the PTF (120-160°C). At the worst condition of the PTF (45°C drop from the separation temperature of 165°C) however, higher deposition rates were measured, with maximum recorded at 150 mg/day (55 g/year).
- Brine treated with F3680 produced yellow slurry and deposits that are less adhesive to the pipe wall. This type of deposit can easily be flushed out with pressurized water.

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