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Silica Inhibitor Hot Injection Test at Bacman Geothermal Production Field, Botong, Philippines

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ABSTRACT

A series of pilot tests were conducted at the Bacman Geothermal Production Field, Philippines, in order to determine the effectiveness of the current silica inhibitor under hot injection conditions. A representative portion of the inhibitor-treated brine was diverted into a series of insulated one-half inch pipes, with retention vessels connected at the end. The test fluid's velocity, retention time, and flow regime were set to mimic the brine's characteristics during the actual hot injection scheme. Results of the latest test showed that at the current inhibitor concentration, dosing rate, brine chemistry, and Fluid Collection and Recycling System (FCRS) parameters, the predicted maximum deposition rate is 20 mm per year along the pipes, and an average of 54 mm per year inside the wellbore. The results indicate that a hot brine injection scheme is technically feasible.

1. INTRODUCTION

The Botong FCRS has been operating under a "low temperature" injection scheme since the start of the commercial operation of the 20-MWe Bacman-II Botong modular power plant in April 1998. The separated brine is being flashed at atmospheric pressure prior to injection. An inhibitor is being used because of the very high silica content of the brine. Without the inhibitor, massive silica deposition would occur immediately along the pipelines (Solis, et.al., 1995). The low temperature injection scheme has so far worked for several years now. However the inhibitor has been proven to be only partially effective at this condition. At the current injection scheme, silica deposition has become a problem. The operation of such scheme has become costly, and beset with some operational difficulties. One alternative solution that is being evaluated is to switch to hot or high temperature injection scheme, with the current inhibitor dosing set-up. This scheme however would require the construction of a new pipeline that would entail significant costs. As part of a thorough technical and economic evaluation process, this test was conducted. The main objective of the test is to determine the effectiveness of the current silica inhibitor under hot injection conditions at the current FCRS parameters and brine chemistry.In mid 1990s a similar test was conducted. In that test the optimum silica inhibitor dosing concentration was established. The initial findings showed that the inhibitor is effective at hot injection condition (Baltasar, et. al., 1997). However only well one production well was utilized during that test and the inhibitor dosing was done directly on a 1-inch experimental line.

In 2007, another hot injection experiment was conducted and yielded promising results (See, 2007). The most recent test was conducted under the present operating conditions in terms of brine chemistry, FCRS parameters and the actual inhibitor dosing set-up and parameters.

2. METHODOLOGY

The experimental set-up is shown in Figure 1. A representative portion of the inhibitor-treated brine from the main injection line near the separator vessel (SV), is diverted into a series of insulated ½" ID BI pipes, about 298 meters in total length, with a series of retention vessels (RVs) connected at the end of the pipes. The purpose of the retention vessels is to prolong retention time, help maintain pressure and water level along the test line, and imitate wellbore conditions. The set-up is designed to simulate the actual hot injection conditions from the separator vessel to the injection well. The duration of the test was forty two days.

Several pressure gauges and mini-thermowells (TW) were placed on strategic locations along the experimental line in order to closely monitor the pressure and temperature. A total of twenty one inspection spools (IS) were also strategically placed along the test line in order to monitor deposition rate. Before the test, similitude calculations were done in order to mimic the actual brine's characteristics in terms of fluid velocity, retention time, and flow regime.

The actual, measured flow rates during the test ranged from 0.021 to 0.18 li/s (ave 0.078 li/s). Based on these measured flow rates, the calculated velocity of the test brine ranged from 0.16 to 0.42 meters per second (average: 0.36 m/s) and this translate to a retention time of 11.8 to 30.9 minutes (average: 13.6 min) along the pipes. The calculated Reynolds number ranged from 2200 to 29572 (average: 23117) indicating turbulent flow. Inside the retention vessels, fluid velocity ranged from 0.0009 to 0.0024 m/s (average 0.0021 m/s), retention time ranged from 34 to 89 minutes (average : 39 min) and Reynolds' number ranged from 323 to 1814 (average 1424) indicating laminar fluid flow.

The test fluid parameters were calibrated and adjusted to simulate the calculated values for the actual brine which has estimated values of *0.4357 m/s, 58 mins, and 610,091* for velocity, retention time and Reynolds' number, respectively. The expected length of the actual brine line is about 1.5 kms, and the inside diameter of the pipeline is ten inches.During the experiment, water level was maintained at the separator vessel on the second week until completion of the test. On the first week, no water level was maintained at the separator vessel due to operational exigency. All FCRS parameters such as separator vessel pressure, brine flow rate, inhibitor dosing rate and concentration, were maintained at actual operation values. Throughout the test, the following parameters were maintained: Separator vessel pressure: 6.2 to 6.7 kscg ; separated brine flow rate : 19 to 21 kg/s ; inhibitor concentration : optimum concentration; inhibitor dosing rate : optimum rate ; production wells status : all wells on-line at full-bore discharge.

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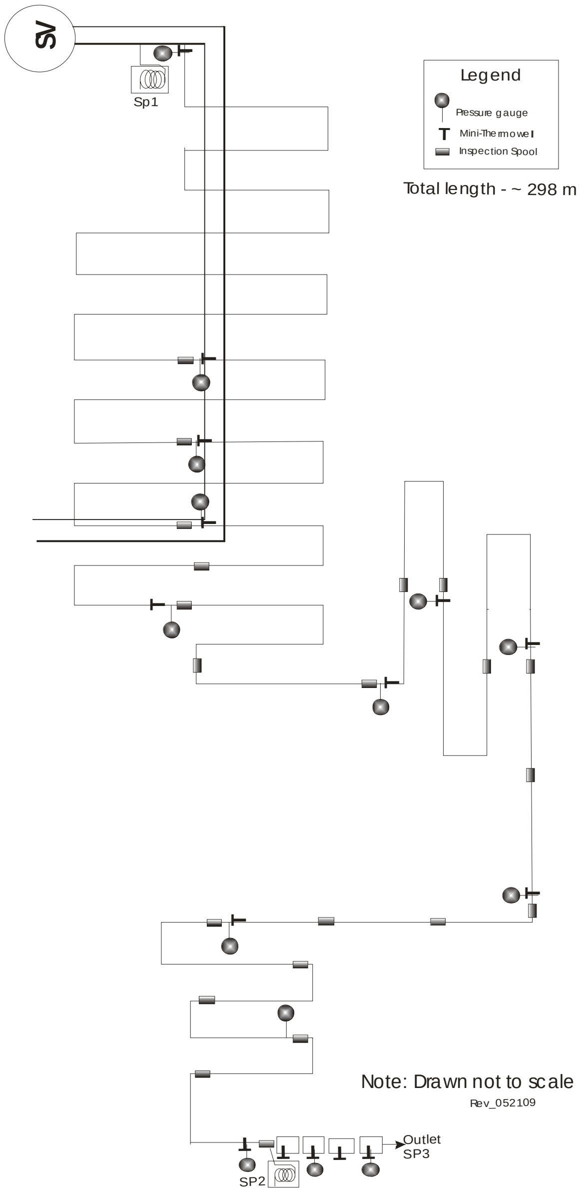

Figure 1: Test Set-Up

3. TEST RESULTS

3.1 Pressure Monitoring (Fig. 2)

Results of the monitoring along the line showed that significant pressure drop was observed from pressure gauge 1 (P1) at 93 psig average, to pressure gauge 2 (P2) at 81 psig average. This pressure drop was probably caused by the 40 ft long smaller diameter SS tubing inserted in the set-up in order to simulate flashing and pressure drop along the pipeline. The smaller diameter tubing may have induced pressure drop at this portion of the line. Such drop however simulates worst conditions. From P2 downstream to P13, pressure was relatively constant ranging from 81 to 78 psig (average). There were also several instances during the test when significant pressure drops were measured along the test line. These occurred when portions of the brine flow was diverted to the silencer, and during bore output measurements when production wells were cut-out, thus significantly reducing the brine flow along the test line. During such conditions test line pressures dropped from 85 to 93 psig at P1 to as low as 44 psig at P14. Such conditions lasted from a few minutes to several hours. These may have caused flashing along the test line, subjecting it to conditions susceptible to silica deposition, again simulating worst scenarios.

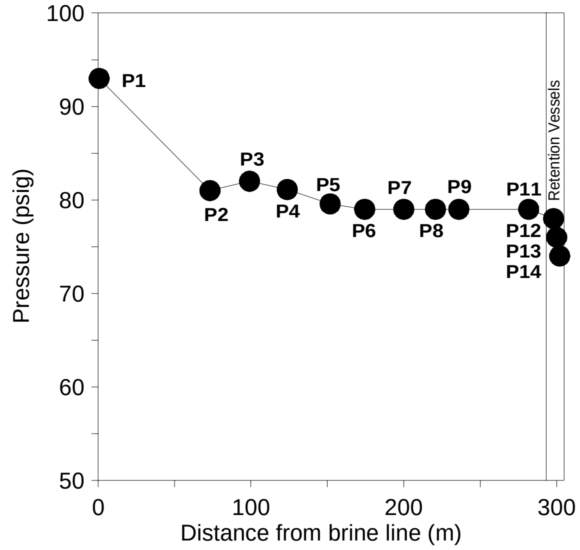

Figure 2: Pressure profile along the test line

3.2 Temperature Monitoring (Fig. 3)

Significant drops in temperature were measured along the line. Average measured temperature decreased from 149°C at TW-1 near the main brine line to 86°C at the last retention vessel outlet (Fig. 3). Average temperature drop from TW-1 to TW-14 was 63°C. These caused significant increase in the silica saturation index, from 1.15 at SP-1 (near the main brine line) to 2.52 at SP-2, near the retention vessel, and 2.74 at the last retention vessel outlet. Although insulation was improved, the low brine flow and frequent heavy rains contributed to significant cooling of the brine along the test line. Such drops in temperatures have subjected the line to extreme conditions favorable to silica deposition. Such condition is again a worst-case scenario being simulated in terms of temperature drop but unlikely to happen during actual brine hot injection.

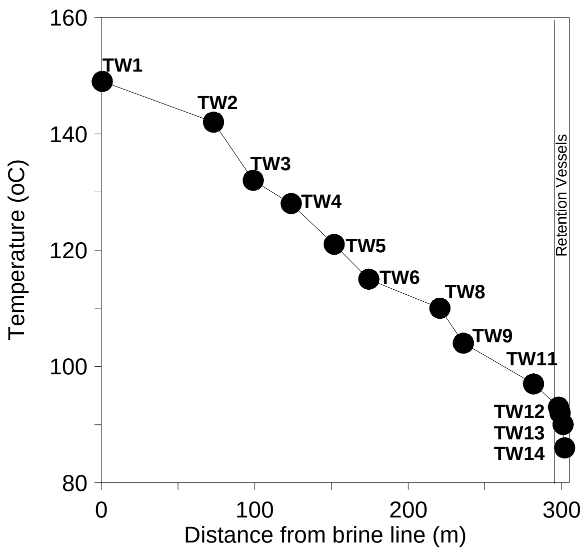

Figure 3: Temperature profile along the test line

3.3 Silica, SSI, and Chloride Monitoring

Silica and chloride concentrations in all sampling points (SP-1, SP-2, SP-3) showed fluctuating trends (Figs. 4a and 4c), indicating fluctuating flow rate and brine chemistry, and flashing along the test line. SiO_2 concentrations ranged from 685 to 900 mg/kg (ave 792 mg/kg) at SP-1, 655 to 860 mg/kg (ave. 772 mg/kg) at SP-2, and 654 to 899 mg/kg (ave 766 mg/kg) at SP-3. Chloride concentrations ranged from

11597 to 12875 mg/kg (ave 12245 mg/kg) at SP-1, 11530 to 13484 mg/kg at SP-2 (ave 12139 mg/kg), and 11631 to 13384 mg/kg (ave 12410 mg/kg) at SP-3.

The silica saturation index (SSI) at SP-1 (Fig. 4b) which is located at the main brine line, consistently showed supersaturated condition ranging from 1.05 to 1.46 (ave 1.15). At SP-2 and SP-3, the SSI levels were significantly higher at 2.54 to 2.74 (average), due to the decrease in temperatures. Without the inhibitor, massive silica deposition is expected to occur at these SSI levels.

Silica concentrations plotted against the sampling points (SP-1, SP-2, SP-3, Fig. 4d), did not yield a definite trend that would indicate progressive deposition occurring along the line. Rather, the trends between sampling points are variable, probably due to fluctuations in flow rates. Over-all, silica concentrations between the sampling are relatively close in values. In terms of chloride concentrations (Fig. 4e), the trend between sampling points is relatively constant indicating that the samples are not steam diluted. Slightly higher values at retention vessel outlet indicate the effect of evaporation. In terms of SSI (Fig. 4f), the significantly higher indices at SP-2 and SP-3 is due to the significant drop in temperature at these sampling points while silica concentration was maintained in the brine.

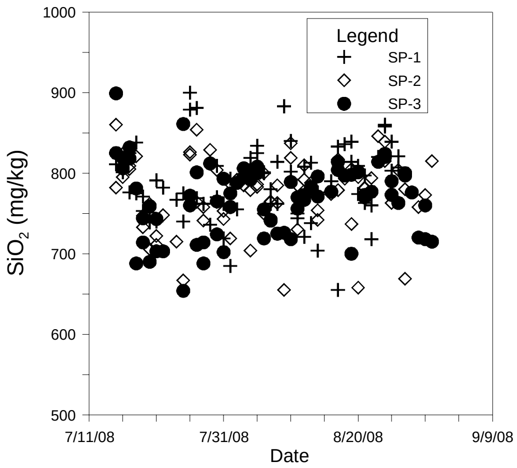

Figure 4a: SiO_2 trend with time

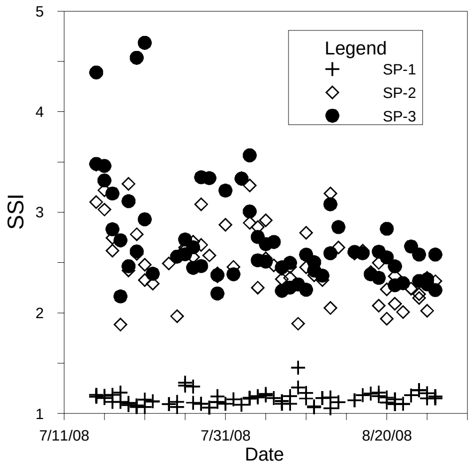

Figure 4b: SSI trend with time

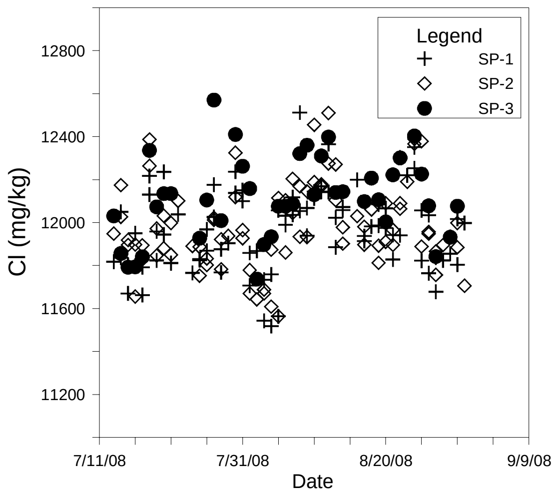

Figure 4c: Chloride trend with time

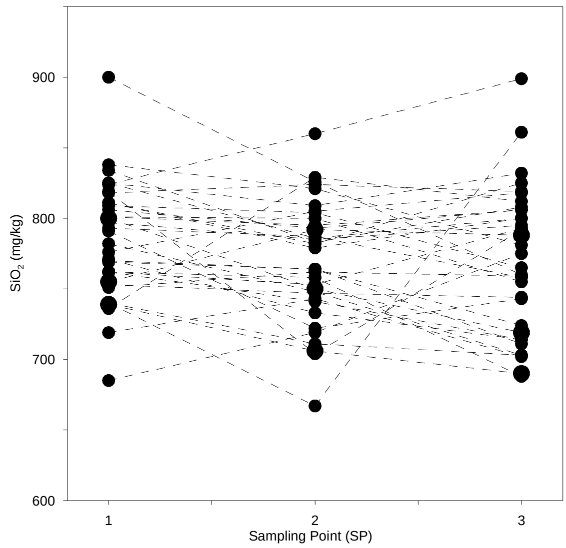

Fig. 4d: SiO2 vs. Sampling Point

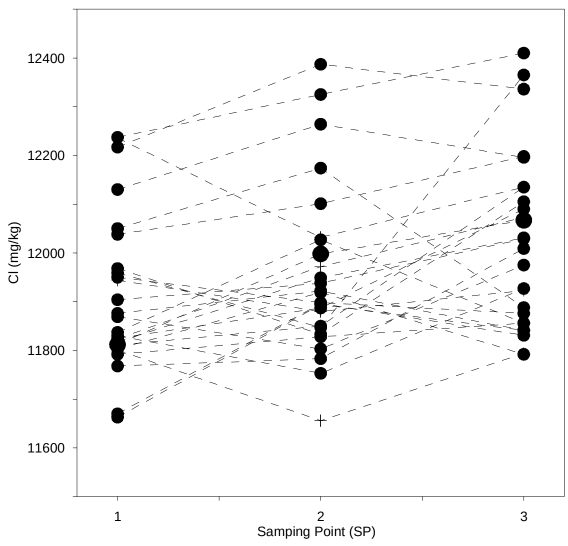

Fig.4e: Chloride vs. Sampling Point

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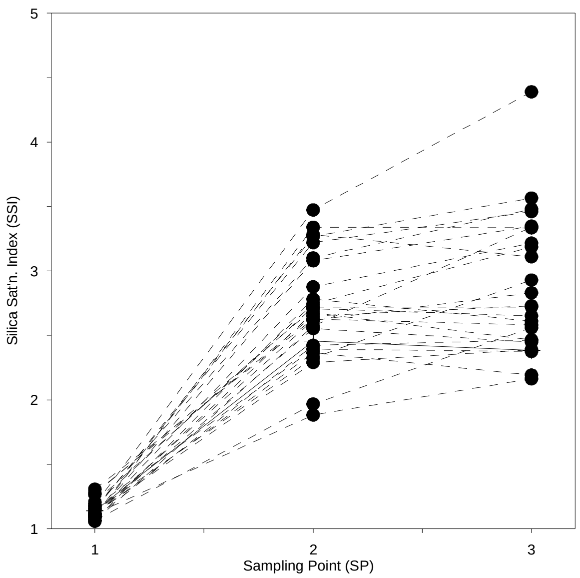

Fig. 4f: SSI vs. Sampling Point

3.4 Deposition Rate

3.4.1 Deposition Rate Along the Pipeline

Results of deposition monitoring after 42 days of testing is shown in Fig. 5. From inspection spool (IS) #1 to 21, thickness of deposits measured using a caliper ranged from 0.13 to 2.23 mm. These translate to projected deposition rates of 1 to 20 mm per year. The highest deposition rate was measured at inspection spool no. 3 (Figure 6), located about 125 meters away from the main brine line and with corresponding measured temperature of about 128^{o}C. Other spools with significant deposits were IS 5 and 6, all located near the portion of the pipe were significant drop in pressure was monitored. Continuous flashing may have caused the higher deposition rates in these spools. However, despite this worst case condition, the projected deposition rate of 20 mm per year maximum is manageable in actual operation. Based on the present injection set-up, the brine flow is handled by a 6" diameter line. So, a reduction of about 1.5 inches in a 10" diameter line would not affect the line capacity; regular cleaning of the pipelines could be done during preventive maintenance schedule.

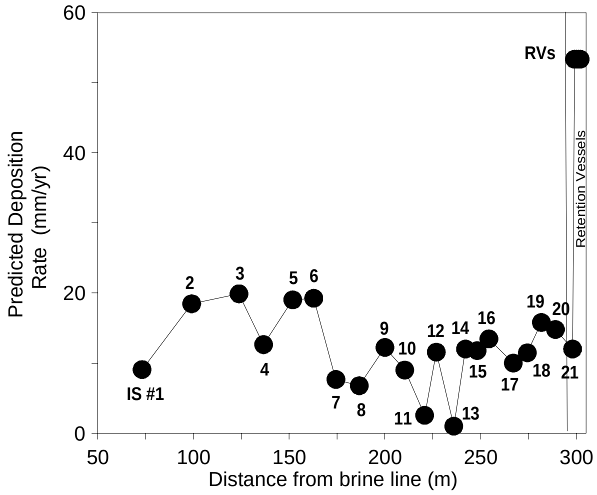

Figure 5: Predicted deposition rates based on inspection spools (IS) and retention vessels (RVs) measurements

Figure 6: Inspection spool no. 3

Downstream of the test line, away from the main brine line, the deposition rates obtained were relatively low despite the significant drop in temperature. This indicates the effectiveness of the current silica inhibitor even at such condition, thus, expectedly more so under high temperature and pressure conditions. Also, no increasing trend in deposition rate along the line was observed as the temperature of the fluid decreases and SSI increases, as could be expected under normal conditions. Again, the silica inhibitor may have played a role in preventing the inducing effect of temperature drop in silica deposition.

3.4.2 Deposition Rate Inside the Retention Vessels

Significant amount of deposits were formed inside the retention vessels especially at retention vessel no. 2 (Figure 7) where thickness ranged from 4 to 10 mm. Overall, the average thickness in the four vessels was about 6 mm; this translates to a projected deposition rate of around 53.5mm per year inside the wellbore. However, the significant amount of deposits inside the vessels were probably caused by several worst-case conditions such as flashing due to the abrupt change in pipe diameter from ½ to 9-inches inside the vessel, laminar flow, and the significant drop in brine temperature to as low as 85^{o}C. The atmospheric pressure at the retention vessel outlet may have also contributed to additional flashing in this part of the set-up. During the actual hot injection scheme, the above scenarios can and should be prevented. For example expected temperature drop from separator vessel to the injection well is less than 5^{o}C; flashing along the brine line could be minimized by maintaining water level at the separator vessel and by operating the lines at flooded condition.

Despite the relatively thick deposits observed inside the vessels, the total amount of deposits collected after 42 days was only 10 liters (at 0.078 li/s average brine flow). Based on this data, and using a simple ratio and proportion calculation, 20 kg /s brine (which is the actual brine flow at Botong) is predicted to produce approximately 22 cubic meters of silica deposits per year. Assuming that all of these will form inside the well bore, a 76-cubic meter injection wellbore (i.e., production casing plus slotted liners) such as the current injection well, would take about three and a half years to fill-up. Since the deposits formed were relatively porous, the wellbore may continue to accept brine even as the deposits are forming. Again, this is assuming worst condition in terms of flashing and temperature drop. If such worst-case conditions can be prevented during actual hot injection, these projected deposition rates is expected to be much lower.

Figure 7: Retention vessel no. 2

3. SUMMARY AND CONCLUSION

The silica inhibitor at the current dosing rate and concentration, brine chemistry and FCRS parameters has been shown to be effective at hot injection conditions with deposition rates estimated at maximum of ~20 mm per year along the pipelines and about 53.5 mm per year inside the wellbore. The higher deposition rates obtained at the retention vessels could be attributed to controllable factors such as pressure and temperature drops, flashing, and laminar flow. Such factors must be controlled and minimized during the actual hot injection scheme in order for the inhibitor to be most effective. Based on the test results, a hot injection scheme with inhibitor dosing is a technically feasible option.

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