

## Silica Polymerization and Deposition Trials at the Berlin Geothermal Field, El Salvador

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### ABSTRACT

The Berlin geothermal field has 56 MWe of power generation from single flashed steam at 180 °C/10 bar abs with full injection of the waste brine.

The brine flow represents a substantial source of unused energy with some 250 MWt (thermal) available for further exploitation. But, the concentration of silica in is quite high, making it necessary to run silica trials in order to test the optimum temperature drop for the maximum generation, considering a minimum risk and cost.

A series of field trials have been recently carried out to characterize silica polymerization and deposition rates in the brine over a wide range of conductively cooled temperatures, with and without chemical treatments. The conceptual design and methodology for the trial are described in detail. The results of the trial confirm the technical and economic viability of installing a brine binary power plant with a capacity of about 10 % of the main plant capacity.

### 1. INTRODUCTION

The operation of the Berlin geothermal power plant at 56 MWe produces a waste brine flow of 350 kg/sec at 11 bar abs and 184 °C. Currently, this flow is reinjected back into the reservoir that represents an unused energy flow of about 250 MWt (thermal).

There is considerable potential to recover a significant amount of this unused energy in this waste brine flow for further power generation. Benefits from this would include improved efficiency of utilization of geothermal fluids and the overall geothermal resource at Berlin and increased generation and revenue for a relatively small additional capital cost because the geothermal wells, steam/brine separators and brine pipe work are already in place, having been earlier funded by the Berlin 1<sup>st</sup> Power Plant Development, however, the amount of additional power that could be generated from the Berlin brine will depend on how much heat can be extracted from the brine before silica scaling becomes a problem.

Silica poses a serious operational constraint in geothermal field operations due to the formation of scales in surface pipes work and the injection wells as the brine cools and ages. The main controls on the tendency of geothermal brine to deposit silica are a number of inter-related variables: temperature of brine, concentration of dissolved SiO<sub>2</sub> in brine, reservoir temperature, brine pH and salinity, presence of cations such as Ca and Mg which can flocculate silica polymers and accelerate scaling and residence time of brine in surface facilities. The key issues in silica scale

formation include: brine in the reservoir is in equilibrium with quartz but brine becomes supersaturated with respect to amorphous due to boiling as the fluid flows up the well, monomeric silica begins to polymerize after a time known as the “induction period”, polymerized silica particles grow in size coalesce, achieve a critical mass and gravity settle, and finally ongoing cementation of silica around the settled particles forms a hard “scale”. The concept of silica polymerization time is very important in that silica deposition cannot occur unless brine is super saturated in silica at any particular temperature and then deposition proceeds only after the monomeric silica begun to polymerize because it is the polymerized particles that give rise to deposition.

There are a number of methods for controlling or mitigating silica scale, including: controlling separator pressure to maintain the temperature of the brine above the silica super saturation temperature, pH modification – either through the addition of mineral acids to reduce the pH (to slow down the rate of the silica polymerization reactions which serves to increase the silica polymerization induction time) or the addition of alkali, such as caustic soda, to increase the pH (which increases the solubility of silica), a number of chemical antiscalants which claim to prevent or reduce silica scaling in geothermal fluids, brine dilution and recovery of silica prior to injection. Barnett and Garcia, 1993.

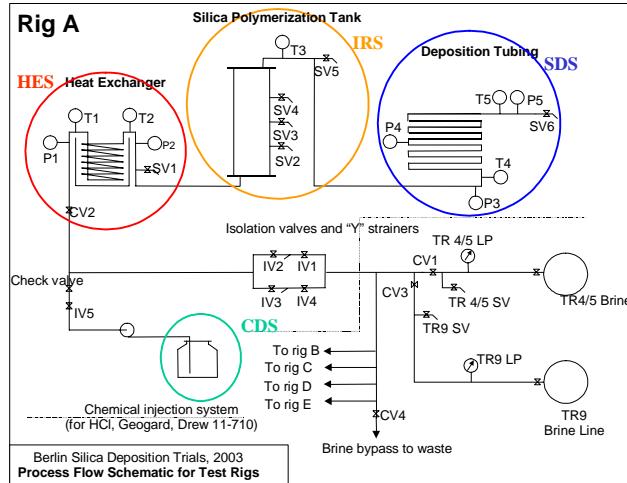
Acid dosing of silica supersaturated geothermal brine to control silica scaling has become quite standard practice in the geothermal industry over the past 5 years. There are a number of silica antiscalant chemicals available which claim to prevent or reduce silica scaling in geothermal fluids. The best documented of these is known as Geogard-SX and this has been tested extensively by PNOC-EDC in the Philippines, with good results being reported (see for example, Garcia et. al, 2000). Geogard is marketed in the Americas as Millsperser SX by Ashland Inc. They also has a silica antiscalant chemical known as Drew 11-170. Both the Millsperser and Drew 11-170 silica treatment chemicals are known as “dispersants” which act to keep long chain silica polymers from coalescing thus preventing particle growth which leads to increased particle mass and eventual deposition

It is not possible to precisely calculate the effect of the above variables on the silica scaling potential of geothermal brine. It is therefore necessary to undertake site specific field trials at any geothermal field in order to assess the lowest practicable temperature that brine can be cooled to before silica scaling becomes unmanageable and the effectiveness and costs of the various treatment options. During 2003, LaGeo S. A. de C. V. formulated and undertook a series of pilot sized silica scaling trials at the Berlin geothermal field test the effectiveness of acid dosing, Millsperser SX and Drew 11-170 at various brine

temperatures. The objective for this work was to optimize the size of a brine binary power plant with respect to silica scaling issues, in the size range of about 5 to 10MWe. This paper briefly describes the methodology used and the results obtained from the trials.

## 2. DESIGN OF TRIALS

Silica polymerization/deposition test rigs (the “rigs”) were built to the LaGeo/SKM design shown in Figure 1. Key objectives with the design were to obtain both silica polymerization and silica scaling rate date with flow rates, residence times and materials typical of actual geothermal binary power plant.



**Figure 1. Process design for silica polymerization and deposition test rig.**

The rigs consist of the following five components:

- Heat exchanger section, HES. Located at the upstream end of test rig. This produces a high temperature drop in the brine, with a relatively short brine residence time thus simulating the brine cooling that occurs in a binary power plant shell and tube exchanger.
- Isothermal residence section, “Polymerization Tank”, IRS. Which simulates the residence time for brine in a steam field reinjection system between a binary power plant and the sub surface injection zone in an injection well where the silica-saturated brine is reheated to above the brine silica saturation temperature. In geothermal brine collection piping systems brine residence times are typically between 30 and 100 minutes, depending on the flow distance between the power plant and the injection well. The residence time in the Berlin test rigs was sized at 60 minutes for a brine flow velocity of 3 m/sec.
- The retention polymerization tank was designed with sample ports for collecting brine samples at 0, 1/4, 1/2, 3/4 and at the full tank height corresponding to 0, +15 minutes, +30 minutes, +45 minutes and +60 minutes of brine polymerization after the initial cooling imposed on the brine in the heat exchanger section.
- The silica deposition section, SDS. It is to assess the deposition tendency of super-saturated silica in the brine that has been aged and polymerized in the IRS. This section has deposition spools consisting of removal stainless steel tubing elements with

“Swagelock” fittings (SS-316L) which were pre-weighed and installed before each new run, and then removed, re-weighed to determine silica deposition rates, and then discarded after each run was finished. The design allowed for installation of different tube diameters so that the affect of different brine velocity on the settling and deposition rates of agglomerating silica particles can be assessed.

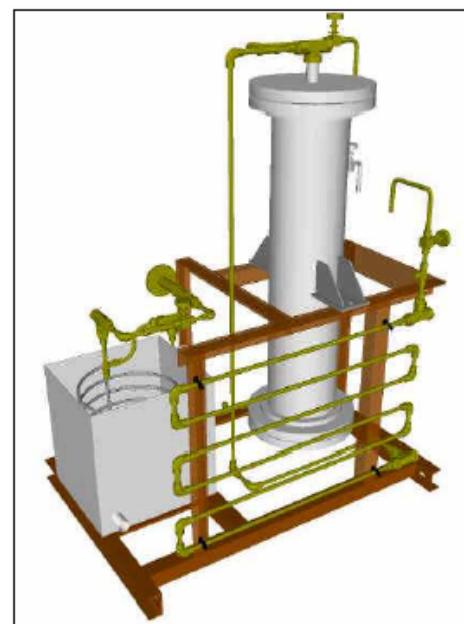
- The chemical dosing system, CDS. It consists of a single piston precise metering chemical dose pump, which is used to inject chemical treatments into the brine upstream of the HES. The pump had fully variable control on both stroke rate and stroke length.

## 3. METHODOLOGY

### 3.1 Polymerization Trials

Five (5) silica tests rigs, figure 2, were built by LaGeo and installed in October 2003 on the TR-9 well pad site at the Berlin geothermal field. Two sources of hot brine were piped up to the rigs, one from the TR 4/5 production well pads and the other from production wells TR-2 and TR-9. The trials commenced in November 2003 and were concluded in February 2004. In total, 46 silica trials were conducted and these were typically of 7 days duration each. In summary the trials undertaken included:

- Untreated brine cooled from a brine line supply temperature of 184 °C to 160, 140, 120, 100 and 70 °C.
- Brine dosed with HCl to pH's of 5.0, 5.5 and 6.0 and cooled to 160, 140, 120, 100 and 70 °C.
- Brine dosed with 5 and 10 ppm of Millsperse SX and cooled to 160, 140, 120, 100 and 70 °C.
- Brine dosed with 10 and 20 ppm of Drew 11-170 cooled to 160, 140, 120, 100 and 70 °C.
- Monomeric silica, pH and Cl values were analyzed directly at the trial site and total silica was subsequently determined in LaGeo's central laboratory.



**Figure 2. Model of silica test rig.**

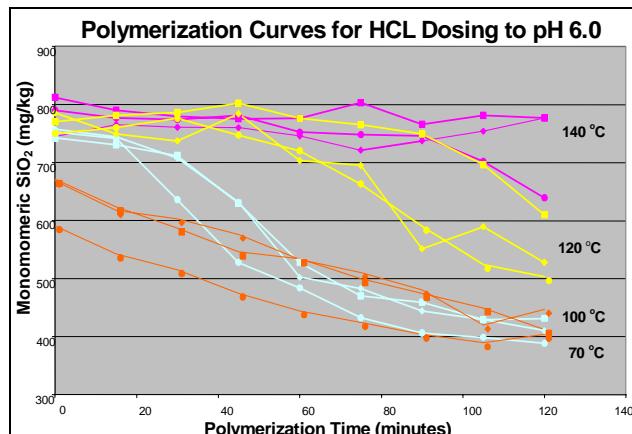
### 3.2 Deposition Trials

At the start of each rig trial, new lengths of  $\frac{1}{4}$  inch and  $\frac{3}{8}$  inch stainless steel deposition tubes were installed in each rig. Brine flow, untreated or treated as required, was then established through the tubes and maintained for typically 7 days. The tubes were accurately weighed both before and after each test with an electronic balance reading to  $\pm 1$  gm. The weight gain in the tubes with time was used to determine silica deposition rates.

## 4. POLYMERIZATION RESULTS

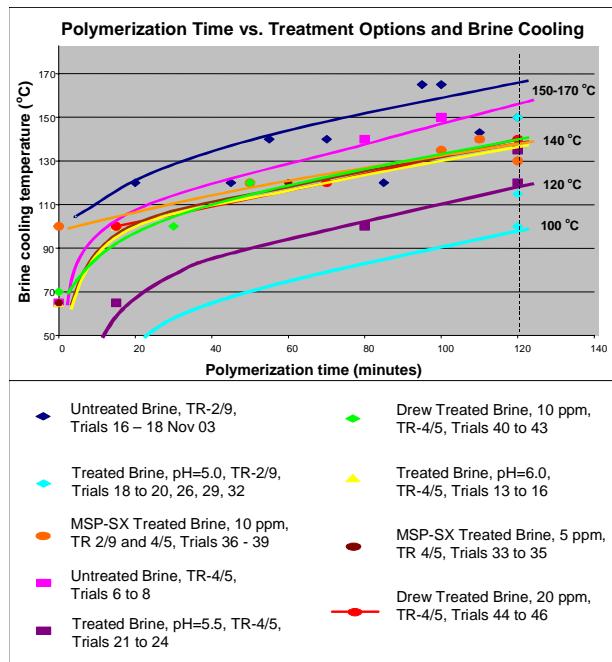
A large amount of silica polymerization data was obtained during the course of the 46 trials. These data were processed and handled as follows:

- Plots of monomeric silica versus polymerization time were prepared for each chemical treatment at each cooled brine temperature. An example plot is shown in Figure 3 for brine dosed to pH 6.0 and cooled over a temperature range of 140 to 70°C.
- From each polymerization curve, the silica induction period was assessed. This is time over which monomeric silica remains stable after cooling was imposed on the brine and prior to the onset of polymerization during which silica scaling can occur. The induction periods varied from zero (e.g. for untreated brine cooled to 70 °C, to greater than 120 minutes for some acid treated and dispersant treated trials.



**Figure 3. Silica polymerization curves for HCl dosing of TR 4/5 brine to pH 6.0.**

The silica induction times for all trials were then plotted against brine cooling temperature for each treatment option as shown in Figure 4. From this figure it is indicated that the time before polymerization commences for the various untreated and treated options varies as detailed in Table 1.



**Figure 4. Silica polymerization times vs. brine cooling for all treatment options.**

**Table 1. Silica Polymerization Times**

Treatment Case	Brine cooling temp. at which onset of polymerization occurs after 60 min.	Brine cooling temp. at which onset of polymerization occurs after 120 min.
<b>Untreated</b>	130 to 140 °C	155 to 165 °C
<b>HCl dosing to</b>		
<b>pH 6.0</b>	120 °C	135 °C
<b>pH 5.5</b>	100 °C	120 °C
<b>pH 5.0</b>	80 °C	100 °C
<b>Millsperser to</b>		
<b>5 ppm</b>	120 °C	140 °C
<b>10 ppm</b>	120 °C	140 °C
<b>Drew 11-170 to</b>		
<b>10 ppm</b>	120 °C	140 °C
<b>20 ppm</b>	120 °C	140 °C

In the case of the untreated and HCl treated brine options, the polymerization times can be taken as the times at which the brines will start to deposit silica and thus these values indicate how much temperature drop the brines can tolerate before deposition becomes an issue within the time frame available in the surface piping and injection system for disposal of the brine. In these results the HCl dosing shows an excellent delays in silica polymerization down to brine cooling temperatures of even 80 °C at pH 5.0. Due to the potential for corrosion of brine pipelines at pH 5.0, the

lower practical brine temperature which could be achieved with HCl dosing is 100 °C at pH 5.5.

In the case of the chemical dispersants, Millisperse SX and Drew 11-170, the onset of polymerization does not necessarily indicate the onset of silica scaling because the action of these chemical is to prevent polymerized particles forming scales rather than preventing or delaying the onset of polymerization which is the case with acid dosing. It is therefore necessary that the deposition data be assessed to determine the efficacy of the chemical dispersants.

## 5. RESULTS OF DEPOSITION TRIALS

Deposition rates in the two tube sizes varied from zero up to 18 grams per tonne of brine under the conditions of the various tests.

It was evident from the untreated brine and the pH 6.0 acid treated brine trials that even a limited degree of brine cooling from 185 to 170 °C resulted in significant deposition (e.g. 200 tonnes of silica per year for a 350 kg/sec binary power plant) if the brine could not be reinjected within 60 to 70 minutes from the time of the cooling. This result was in contrast to the polymerization results in Table 1, which indicate that deposition would not be a problem over a time frame of at least 120 minutes for brine cooled down to 155 to 165 °C.

Results of the measurement of silica deposition rates in 3/8" and 1/4" deposition tubes for chemically treated brines are given in Table 2, for both stronger doses of acid and the Drew and Millisperse chemicals. These are arranged in order of most effective control on deposition rate through to least control. From these data it is evident that:

- Excellent control on silica deposition was obtained at all brine temperatures for the pH 5.0 HCl dosing trials.
- Good control on silica deposition was obtained with HCl dosing to pH 5.5, Millisperse 5 ppm and Drew 20 ppm dosing down to temperatures of 100 °C and lower, but with scaling rates of some 2 to 3 times that for the HCl pH 5.0 trial.
- Less effective control on silica deposition was achieved with Millisperse 10 ppm dose rate. Scaling rates for this treatment at 100 °C were 4 times higher for the 3/8 inch tubes than for the HCl pH 5.0 dosing trials.

## 6. CONCLUSIONS

Based on the results of the trial, we conclude that:

- a. Brine dosing of the Berlin brine with HCl to pH 6.0, 5.5 and 5.0 is effective in controlling the onset of silica polymerization and silica scaling. Brine dosed to pH 5.0 will lead to corrosion issues thus an operating pH range of 5.5 to 6.0 for a future brine power plant at Berlin is indicated as being appropriate. The measured scaling rate at pH 5.5 is somewhat

better than at pH 6.0. At the upper limit of pH 6.0, the brine can be cooled and held at 130 °C for 120 minutes before silica polymerization and silica scaling becomes an issue.

**Table 2. Results of Silica Deposition Trials**

Tubing Size (inch)	Brine Treatment Option	Range in Silica Deposition Rates	
		From	To
1/4	HCl, pH 5.0	1 g/t at 150 °C	1 g/t at 90 °C
	HCl, pH 5.5	1 g/t at 150 °C	3 g/t at 90 °C
	Millisperse 5 ppm	3 g/t at 120 °C	3 g/t at 65 °C
	Drew 20 ppm	1 g/t at 140 °C	5 g/t at 100 °C
	Millisperse 10 ppm	1 g/t at 140 °C	12 g/t at 90 °C
	Drew 10 ppm	Insufficient data to assess	
3/8	HCl, pH 5.0	1 g/t at 150 °C	1 g/t at 90 °C
	HCl, pH 5.5	1.5 g/t at 150 °C	1.5 g/t at 65 °C
	Millisperse 5 ppm	1 g/t at 120 °C	2 g/t at 65 °C
	Drew 20 ppm	1 g/t at 140 °C	3 g/t at 100 °C
	Millisperse 10 ppm	1 g/t at 140 °C	4 g/t at 100 °C
	Drew 10 ppm	Insufficient data to assess	

- b. Dosing with both of the chemical dispersants over the dose rates tested here also provides good control on silica scaling. Ultimately the choice of whether to use HCl or dispersants comes down to the question of chemical costs.
- c. Without any form of chemical treatment, the 350 kg/sec brine flow available at Berlin at 184 °C could be safely reduced to about 160 °C without concern for silica scaling. This would be sufficient to power a binary plant of about 5 MWe size.
- d. With the results of the trials reported here, LaGeo is now planning to proceed with an optimized binary power plant based on:
  - A brine inlet temperature of 184 °C
  - A brine outlet temperature of 140 °C
  - Acid dosing the brine with HCl to maintain a pH of between 5.5 and 6.0.

This will be sufficient heat to power a binary plant of about 11 Mwe (gross). The future economic benefit to LaGeo of the silica trials reported here is therefore likely to be significant

## 7. REFERENCES

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