



PREVENTION OF SILICA SCALE FORMATION IN GEOTHERMAL ENVIRONMENTS USING CHEMICAL METHODS

Oliver T. Jordan, S.E. Garcia, R.V. Macambac, R.C. Gonzalez, R.C.M. Malate, and J.R. Ruaya
PNOC-Energy Development Corporation,
Merritt Road, Fort Bonifacio, Makati City,
PHILIPPINES

ABSTRACT

Chemical additives designed and formulated to inhibit the formation of amorphous silica deposits from geothermal waste waters were extensively tested in a pilot facility using separated water from well 501 in the Leyte Geothermal Power Project, Philippines. After a series of tests involving three additives, only the 3rd polymer (DP3439) resulted in a significant reduction of amorphous silica deposition from the geothermal brine. Results of the trials which were conducted using 152.4 mm pipes with brine at very low flow rates of 1.5-5.4 kg/sec and at extremely high silica saturation indices of 2.3-2.5 have shown DP 3439 to achieve 38% to 96% inhibition efficiency at varying low concentrations. The results of the experiments are promising not only as a potential solution to the perennial problem of amorphous silica deposition in surface pipelines and reinjection wells, but also in terms of the enhanced flexibility in adopting lower production separation pressures to increase steam recovery, reduce non-condensable gases and injection capacity requirements.

1. INTRODUCTION

Experience in the operation of two-phase flash plants of the Tongonan, Leyte and Palinpinon, Southern Negros geothermal fields, Philippines, for the past 13 years has shown that the formation of silica scale deposits severely restricts reinjection line and well capacities. Remediation has been either through mechanical scale removal in pipes lines and in reinjection wells, construction of redundant reinjection lines, reinjection line pH modification, well acidizing or replacement well drilling, or a combination of these. The disadvantage of these methods, aside from cost, is the inevitably lengthy decommissioning of the reinjection line or well, i.e., putting it out of service. For power plants on base load operation, such down periods equate to revenue losses. In the Palinpinon-1 field, for example, de-scaling of reinjection line 317 took seven months prior to re-commissioning (Virata, 1987). Avoiding or reducing silica scale formation to within manageable levels has been the subject of experiments in many geothermal fields. No method has yet been universally accepted as both technically and economically feasible in long-term and field-wide applications.

This paper describes experiments conducted on newly formulated inhibitors designed to address the problem of silica scale formation in geothermal waters (chemical inhibitors generally are polymers or copolymers of acrylic acids and acrylates). The use of inhibitors offers a significant advantage over other

methods of deposition prevention in that the deposition process is actually inhibited, and not merely retarded (as in line pH modification). Also, the equipment and support facilities required incidental to this method are minimal in terms of cost. Furthermore, under proper conditions of application, the inhibitor is classified as environmentally acceptable (category zero).

The objectives of the experiment were to determine if the inhibitor works, identify the optimum range of operating conditions and inhibitor concentrations and evaluate the economics of utilization. The experiment was the product of a joint, cooperative research effort between PNO-C Energy Development Corporation and FMC Process Additives Division, based in Manchester, England, the formulator and sole manufacturer of the chemical inhibitors tested. Laboratory tests were conducted and confirmed by FMC on the thermal stability of these inhibitors over the operating temperature range of the brine in the pilot test facility. Initially, the experiment was to be conducted by replicating the conditions in the existing Fluid Collection and Disposal System (FCDS) of PNO-C in its geothermal fields on a smaller scale. Necessary were an available production well that could provide a wide range of operating conditions, as well as a reinjection well located relatively close to the selected production well. The Malitbog sector of the Leyte Geothermal Power Project has a pilot testing facility (Malitbog testing facility) which fit the above requirements. The area has a production well (501) and a reinjection well (5R7D) and the pipelines to be installed could easily replicate the FCDS. The experiments were conducted from October 1992 to July 1994.

2. EXPERIMENTAL DESIGN, MAIN TESTS

The experimental process flow diagram is shown in Figure 1. Well 501 discharged into a separator vessel at fixed wellhead and separation pressures. The water, after separation, was split equally into two parallel lines where one line served as the untreated or blank line ("B"), and the other was dosed at a constant rate with the additive inhibitor ("A"). The waters then converged into one line and either reinjected back into well 5R7D or were allowed to discharge into the environment at restricted flow rates. Under these conditions, the pipelines would always be full of water, and the water flow rate and velocity could be controlled. Furthermore, the silica saturation index, (defined as the ratio between the measured silica content at separation pressure and the theoretical silica content at the equivalent separation temperature)

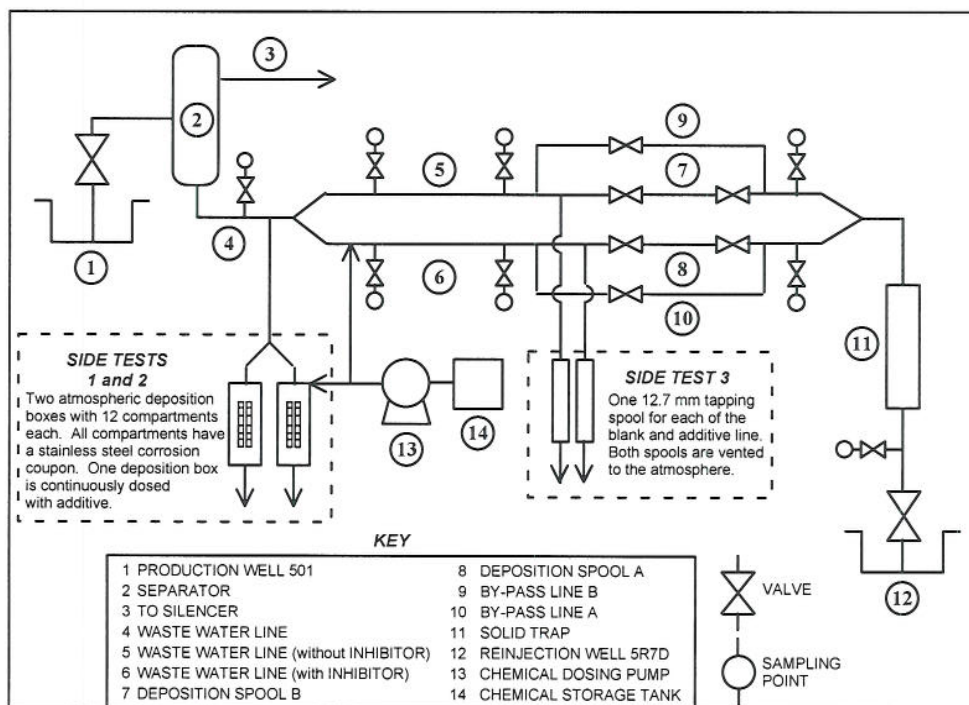


Figure 1: Experimental design and schematic set-up of Malitbog test facility.

could also be held constant. The flow regime in this pilot experiment indicates turbulent flow (calculated Reynold's number of 1.15×10^6 to 4.3×10^6) which was also the case in the main lines. After a discharge test interval (usually ranging from 2 weeks to 1 month), the deposition spools in all lines were inspected to document the comparative rate and magnitude of silica scale build up. The additive line concentration (after the stock solution and reinjection line fluids were mixed) was calculated by mass balance equation from the accurately known dosing flow rates, inhibitor stock solution concentration, and water flow rates. The water flow rate was measured regularly using $MgCl_2$ injected as a tracer, a technique developed by PNO. The primary parameters used to evaluate the inhibition efficiency of the additives were the measured scale thicknesses and the silica particle size measurements in fluids in both lines by Scanning Electron Microscopy (SEM).

It was initially thought that the reaction mechanism governing the inhibition process was the inhibition of monomeric silica from transforming into the polymeric state. Thus, during the early stages of the experiment, total and monomeric silica at selected points down both lines were frequently measured. All data generated, however, consistently showed that the rate of monomeric silica decline in both lines was independent of the additive. This parameter was, therefore, disregarded as a measure of additive inhibition efficiency.

3. EXPERIMENTAL RESULTS, MAIN TESTS

Three chemical additives were tested in the Malitbog facility labelled (code named) as DP 3406, Bellasol S-21, and DP 3439, respectively by FMC. DP 3406 was tested at elevated line concentrations (100 ppm), but results showed that it induced scale formation of hydrated amorphous silica as confirmed by various spectroscopy techniques. Testing of Bellasol S-21 followed at lower concentrations (10 ppm), but with the same results as DP 3406. Thus, further testing of these 2 additives was terminated. These initially discouraging results prompted a review of the chemical formulations and a third polymer, (DP 3439) was re-formulated, and subsequently tested.

Three different line concentrations were considered using DP 3439 at concentrations 5, 8 and 10 ppm. The concentrations were selected, based on an initial cost comparison within a specific time duration, using chemical inhibitors against the other methods of scale removal. At concentrations greater than 10 ppm, the chemical method is no longer justified because of greater cost based on its current price.

The experimental conditions are shown in Table 1. The separation pressures were kept as low as possible to obtain high silica saturation indices of 2.3-2.5 and, thus, minimizing the time needed to induce silica scaling in the blank line. The waste water flow at concentrations 5 and 10 ppm were strictly maintained at an average of 3 kg/s. In the 8 ppm tests, the flow was unavoidably higher due to other testing requisites. The dosing flow rate of the inhibitor, in this case, was increased so that higher flows did not affect the required line concentration.

Table 1: Experimental conditions at different line concentrations using DP 3439, main test

Experimental conditions	DP 3439 line concentration		
	5 ppm	8 ppm	10 ppm
Well head pressure (Mpa)	3.5	3	3.2
Separation pressure (Mpa)	0.143	0.095	0.143
Water flow (kg/s)	3	10.8	3
Fluid temperature (°C)	110	105	110
Residence time (min.)	~8	~5	~8
Silica saturation index	2.3	2.5	2.3
Duration of test (days)	2	30	42
Reynolds' number	1.15×10^6	4.3×10^6	1.15×10^6

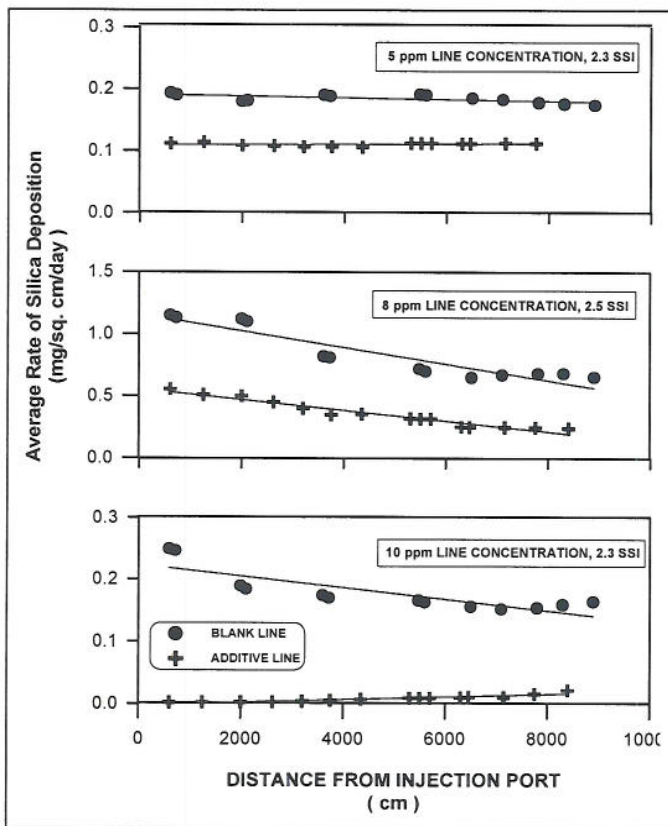


Figure 2: Average silica deposition rate at different DP 3439 concentrations, main test

From the results of the line inspections conducted after each experimental pass, the average rate of silica deposition were calculated from the average scale thickness for each of the spools along lines A and B (thickness was measured at the upstream and downstream ends of the spools) and inside the 152.4 mm pipes, and plotted against distance from the injection point. This is shown in Figure 2.

The deposition rate trends for the treated line was largest at 8 ppm, and lowest at 10 ppm concentration, respectively, but always significantly and consistently less than the blank line.

The scale samples in each spool were collected and subjected to petrochemical analysis after each experimental pass. The analytical results confirmed that the bulk composition of the scale in both lines is indeed silica (38-93% by volume) with some corrosion products (Fe_2O_3 , ranging from 9-58%vol). Comparing the scale thickness of the treated lines with that of the blank line, the average inhibition efficiency of the additive was calculated to

be 38, 65 and 96% for 5, 8 and 10 ppm concentrations, respectively. This is shown in Table 2. From the calculated average rates of deposition, the additive line concentration and the silica saturation indices (SSI's) for each experimental pass, a correlation was established between these three parameters using a linear relationship. This is shown in Figure 3. It is noted that significant rates of silica deposition did not start until at SSI values of 2.3 and higher.

Table 2: Calculated inhibition efficiency of DP 3439 at different concentrations, main test

Polymer DP 3439 Line concentration	% Efficiency	
	Range	Average
5 ppm	37-39	38
8 ppm	60-68	65
10 ppm	91-99	96

*at 2.3 SSI

** at 2.5 SSI

The main reaction mechanism believed to govern the process is the inhibition of polymeric silica from reaching a critical particle size in which deposition starts to occur with subsequent maintenance of a dispersed colloidal condition. This mechanism was deduced by comparing the particle size of the silica molecule in both lines by SEM. Due to operational constraints, however, only selected samples in the 8 ppm tests were subjected to SEM. The results, nevertheless, were conclusive enough in that the particle size in the blank line fluids were larger than in the treated fluids for the same area and magnification.

It can be concluded from these results that the polymer DP 3439 can effectively inhibit the growth of amorphous silica scales between 5 and 10 ppm line concentrations with a 65-96% efficiency, and at silica saturation indices of 2.3-2.5.

4. EXPERIMENTAL DESIGN, SIDE TESTS

Smaller scale tests were designed and conducted to this polymer at similar conditions as in the main tests to generate results with shorter discharge test durations and to provide an independent counter check of the main test results. The schematic diagram of the experimental set-up for the three side tests are shown in Figure 1, while the experimental conditions are shown in Table 3. In side tests 1 and 2, the process flow involved the channelling of a controlled flow of fluid through a 12.7 mm sample point tapping from the 154.2 mm waste water lines (before the Y-split). The fluid passed into a deposition box under atmospheric conditions. The box has a dimension of 1000 x 500 x 76 mm divided into 12 equal compartments.

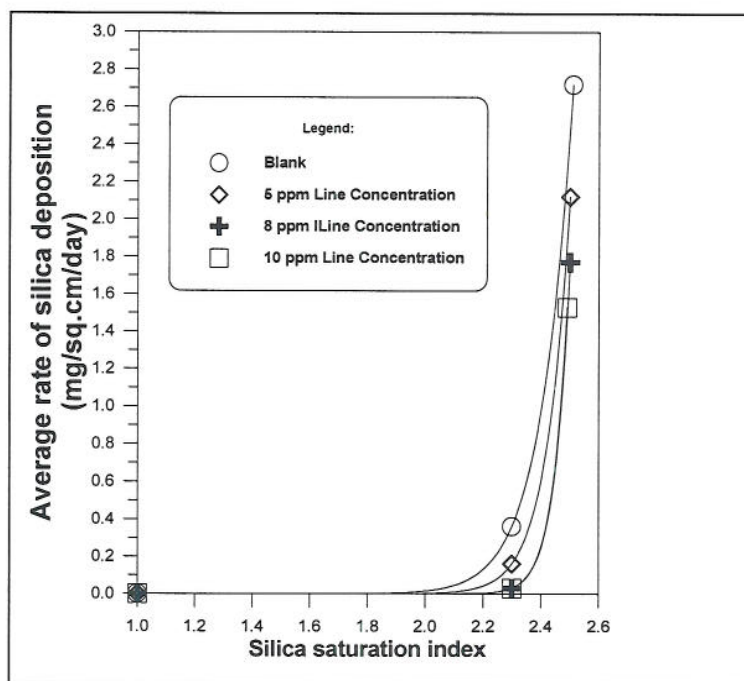


Figure 3: Silica deposition rate as a function of silica saturation index, main test

Table 3: Experimental conditions at different line concentrations, side tests.

Experimental conditions	Side test No.		
	1	2	3
Well head pressure (MPaa)	3.5	3.0	3
Separation pressure (MPaa)	0.143	0.095	0.095
Water flow (ml/min.)	54	49	-
Residence time (min.)	5.4	5.4	-
Silica saturation index	2.35	2.45	2.45
Duration of test (days)	5.1	6	26

Pre-weighed deposition coupons (9.5 mm diameter and 50.8 mm long grade 316 stainless steel tubes) were positioned and totally submerged in each compartment, and flow tests with and without the chemical additive were conducted. After a certain period of flow (5-8 days), the coupons were retrieved, dried in an oven for 2 hours, stored overnight in a dessicator and quantitatively weighed. The mass of silica deposited in each coupon is obtained by weight difference. The inhibitor efficiency for side tests 1 and 2 was determined (1) by the difference in mass and (2) by the calculated average mass deposition rates against distance from the dosing point. The latter was calculated from the mass of silica deposited in each coupon, the inside surface area of the coupon, and the actual discharge test duration.

One objective of side test 3 was to determine the effect of fluid velocity in silica scale build-up. The 12.7 mm diameter spooled pipes reduce water flow rates but increase fluid velocities over the same saturation indices and dosing concentrations. Side test 3 consisted of a 12.7 mm diameter spooled G.I. pipe tapping in both lines A and B about 90 m downstream from the dosing point, and vented into the atmosphere. After a flow test of 26 days, the pipes were opened up and scale thicknesses were measured in each spool. The inhibitor efficiency was evaluated using the same method as in the main test.

5. EXPERIMENTAL RESULTS, SIDE TESTS

Figure 4 show plots of the calculated average rate of silica deposition against the deposition coupon number (which is also a function of the distance from the point of dosing) in side tests 1 and 2. (No experimental passes were conducted for the 10 ppm line concentration, as the side tests were done separately by FMC and were contained in a separate internal report

It is indicated in the plots that a significant difference in the average rate of silica deposition is consistently shown in both concentrations (5 and 8 ppm) against that in the blank line. The 8 ppm test yielded the least rate of silica deposition compared to that in the 5 ppm. The blank line yielded the highest rates of deposition, and variations in rates directly attributable to variations in silica saturation indices were measured. Using the figures of cumulative mass of silica deposited in the additive run against the blank run, the inhibitor efficiency was calculated to be 38 and 96% for line concentrations 5 and 8 ppm, respectively (Table 4). This is generally consistent with the calculated additive efficiency from the main tests.

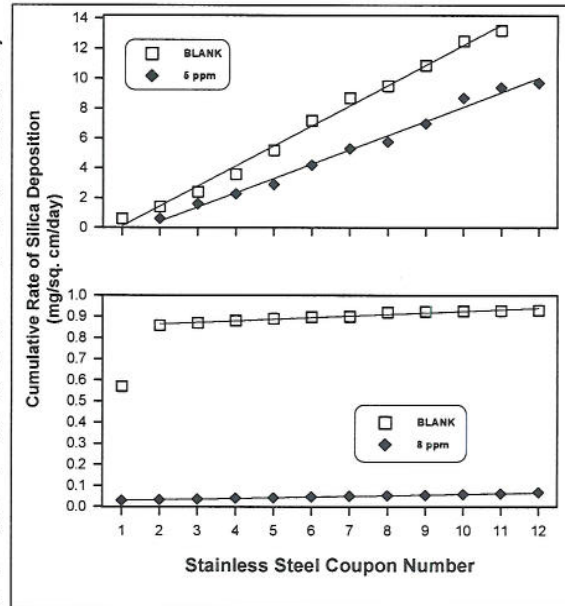


Figure 4: Silica deposition rate against coupon number, side test 1 & 2

Table 4: Calculated silica inhibition efficiency of polymer DP 3439 at line concentrations 5 and 8 ppm, side tests 1 and 2

DP 3439 Line concentration	% Efficiency (average)
5 ppm	38
8 ppm	96

Side test 3 results of the spool thickness measurements after 26 days of continuous testing are shown in Figure 5. The additive line showed very minimal scale deposits, while the blank line showed scale thicknesses ranging from 1-2 mm. The results indicate that the additive efficiency is almost over 99 percent. This general higher efficiency rating is attributed to increased fluid velocities due to smaller pipe diameters than in the main 152.4 mm pipes. The implication of this result is that in the main reinjection lines, where fluid velocities are higher, the rate of silica deposition will be lower which will reduce the inhibitor line concentration requirement.

6. EXPERIMENTAL RESULTS AND OPERATIONAL IMPLICATIONS

Some operational implications of crucial importance are forwarded. From the relationship established between the average silica scale thickness produced

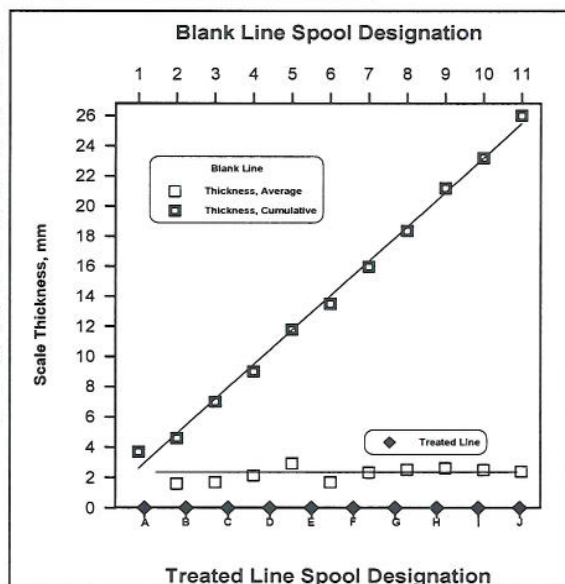


Figure 5: Silica deposition (thickness) at blank line, and 8 ppm of polymer DP 3439

starting from the blank to the highest inhibitor line concentration (10 ppm), the fixed silica saturation index for each test and the calculated average rate of silica deposition.

Even at a very high silica saturation index of 2.3, the average rate of silica deposition is a minimal 0.03 mg/cm²/day for a 152.4 mm pipe with the inhibitor. Projecting this rate of deposition to the reinjection system (say in Tongonan I where pipe diameters are larger (355.6 mm), silica saturation indices are way lower (1.2-1.4) and fluid velocities are higher) suggests that it is safe to operate the reinjection lines at higher silica saturation indices (i.e. lower separation pressures), provided that the inhibitor line concentration is maintained at 8ppm, or even at lower levels. Another factor that will justify the suitability of applying these results to the main system is the fluid velocity factor. The actual velocities in the main system are higher than in these experiments which may allow for reduced additive concentrations than those used in these trials.

Furthermore, the main operational benefits associated with the flexibility to operate at high silica saturation indices are several, namely: (1) separation pressures and temperatures can be lowered, generally allowing for more steam extraction and potentially increasing the opportunity for higher generation from additional second brine flash or binary power plants; (2) lower water fractions consequent to lower separation pressures will require fewer reinjection wells to dispose of the waste liquid; (3) non-condensable gases in the steam phase will be reduced; and (4) de-commissioning of reinjection lines or wells are no longer necessary.

Thus, aside from the immediate operational benefits of reducing well maintenance and replacement costs and preventing loss of line and well capacities, the above major advantages would strongly favor the use of chemical methods in preventing amorphous silica deposition over other techniques.

7. SUMMARY AND CONCLUSIONS

The main reaction mechanism governing the process appears to be the inhibition of polymeric silica from reaching a critical particle size and its subsequent maintenance of a dispersed colloidal condition, rather than preventing the occurrence of the polymerization process itself. As long as this critical size is inhibited, solid deposition can be prevented not only in the surface brine lines, but also down the reinjection wells and to the formation. The results of both the main and side tests consistently indicated increasing silica scale inhibition efficiency of polymer DP 3439 at 38, 65 and 96%, respectively, at correspondingly increasing line concentrations of 5, 8, and 10 ppm, and at silica saturation indices of 2.3-2.5. It can thus be declared that DP 3439 can effectively reduce amorphous silica deposition in geothermal waste water lines and wells to operationally acceptable levels even at such high saturation indices.

Projecting the results of this pilot experiment to the physico-chemical conditions of the main facilities of the Fluid Collection and Disposal System (FCDS) of PNOC-EDC will mean that even lower concentrations of this inhibitor can be utilized, likely with the same results. This further implies that the cost of using this technique could be lower in the less severe fluid conditions in the main reinjection lines. In terms of both technical and economic aspects, the use of this chemical additive to address the perennial problem of dealing with silica deposition in geothermal waters is worth pursuing, the primary thrust now of which is application to the main system, and over a wider (higher) range of geothermal brine silica concentrations.

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