Comparative Study of Silica Inhibitor Versus pH Modification in the Geothermal System

Arsyan Sasoni[1], Anggara Wibawa[6], Nur Choiri Amin[1], Logan Muller[3], Megan Low[2], Michael Bluemle[4], Michael Todd[4], Muhammad Thasril[5], Hanifah Azizah[5], Efrata Meliala[5]

[1]PT. Solenis Technologies Indonesia, Indonesia

[2]Solenis Singapore Pte Ltd, Singapore

[3]Solenis New Zealand, Auckland, New Zealand

[4]Solenis LLC, Wilmington, DE, USA

[5]PT. Geo Dipa Energi, Indonesia

[6]PT. Trisan Samoa Indonesia, Indonesia

asasoni@solenis.com

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ABSTRACT

In the cold injection system of Geo Dipa Energi (GDE) Dieng Unit, amorphous silica deposition remains a significant challenge. Amorphous silica deposition can be detrimental and require costly cleaning of the piping in the surface equipment and injection well.

Historically, pH depression with sulfuric acid (H_2SO_4) has been used to delay silica polymerization. However, the addition of sulfuric acid can lead to severe corrosion problems within the plant, and this has led to the development of alternative approaches to reduce silica deposition.

This paper documents the results from a series of field tests that were conducted to optimize the performance of a new silica inhibitor DPI-920. Key performance indicators were: Brine transfer pump discharge pressure, Silica inhibition percentage, and deposition rate.

The new silica inhibitor yielded significant improvements and an economic benefit of close to 20% versus sulfuric acid (annual projection)

1. INTRODUCTION

One of the current limitations to developing geothermal resources for electricity generation is silica scaling in the associated plant and pipework as the brine is cooled and silica becomes oversaturated.

The table below shows how silica is "lost" across the plant due to polymerization and deposition when no treatment is applied

Table 1: Silica concentration across the plant with no chemical addition (Data provided by GDE)

SNI Method (0,45 micron)	
Sampling Point	**SiO2 (ppm)**
After Separator	902
After AFT (Atmospheric Flashing Tank)	443
Open Channel	250
Thermal Pond Inlet	247

Historically, sulfuric acid (H_2SO_4) has been injected to decrease the brine pH to a point where silica polymerization and deposition is at a low and acceptable rate. However, the injection of acid is technically difficult and must be carefully controlled to achieve the desired pH. Dosing with insufficient H_2SO_4 results in the deposition of silica whereas too much sulfuric acid causes severe corrosion problems.

In this plant trial silica was monitored at 5 sampling points across the plant to assess silica loss / inhibition. The insertion of scale coupons was used to monitor deposition rates and discharge pressure of the brine transfer pump was monitored to assess deposition in the 3 km pipeline to the reinjection pond.

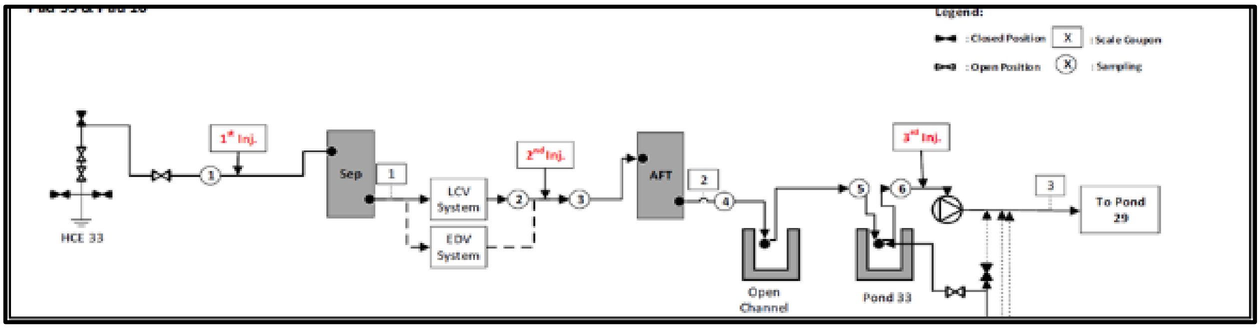
The chemical program was applied under trial conditions for approximately 3 months.

2. BACKGROUND

GDE has a geothermal power plant located in Dieng, Central Java, Indonesia. This one-unit power plant has a capacity of 60 MW and has been operating since 2002. It has experienced scaling problems both on the surface and in the sub-surface.

The production brine (2-phase) enters a single flash system with the separated brine then flowing to an atmospheric flash tank, the brine then flows through an open cooling canal and is finally transferred 3km into a pond system before ultimately being reinjected at a temperature of 40-60 °C. See flow diagram below.

Figure 1: The flow diagram of well pad #1 shows six brine sampling points but during the operation only five sampling points were used as sampling point No. 4 was unavailable. The scale coupon port #3 was moved to before inlet AFT due to operational issues.



3. EVALUTION METHODS

To evaluate the deposition rate, scale coupons were installed after the separator (#1), at the inlet to the AFT (#2) and at the AFT outlet (#3). Brine samples were collected at five collection points for field chemistry measurements and laboratory analysis. (See Figure 1). Three chemical injection points were available as shown in the flow diagram in red font.

3.1 Coupon Exposure Method

The mass-gain coupon exposure method is by far the most frequently used method for geothermal scaling trials. The mass-gain technique was calculated by exposing metal coupons, made of material similar to that of the pipework, to the geothermal fluid for a given duration and then retrieving the coupons for inspection, cleaning, and weighing.

3.2 Silica Measurement

Measuring silica concentration in geothermal brine samples requires an understanding of silica chemistry and attention to analytical detail. Soluble silica consists of both monomeric silica ($SiOH_4$) and polymerized silica $[(OH)_3Si\ \text{-}O]_n$. Freshly taken samples are filtered (0.45µm) and acidified with nitric acid (1.5% HNO3) to prevent any further polymerization of monomeric silica to polymerized silica as the sample cools. The sample is then analyzed using the Hach colorimetric method for monomeric silica concentration.

SiO2 analyses were performed routinely on-site to assess inhibition %. Any decrease in SiO_2 concentration indicates loss of monomeric silica due to deposition or polymerization.

3.3 Key Performance Indicators

Both Solenis and GDE agreed to set KPI to control the % inhibition based on monomeric silica measurement at 5 sampling points or a scaling rate <1 mm/yr. The sample points refer to Figure 1. These key performance indicators are summarized in Table 2.

Table 2: Key Performance Indicators

No.	Sample Point	Location	KPI
1.	Sample 1	2 Phase Before Injection Point	As the Baseline for sample 2
2.	Sample 2 (KPI 1)	Separator Outlet	> 95% and Baseline for sample 3
3.	Sample 3 (KPI 2)	AFT Inlet	> 95%
4.	Sample 4	Thermal Pond Outlet	Baseline for sample 5
5.	Sample 5 (KPI 5)	Inlet Pond	> 90%
6.	Delta Pressure	Brine Booster Pump	< 2Bar

4. RESULTS

The field evaluation was carried out for 3 months which can be divided into two periods. The first period (October) was the most challenging since the plant experienced operational issues and the dosing systems had not been fully commissioned, whereas there were no issues in the November-December period.

4.1 October Period

Inhibitor injection began on October 2nd, 2023. During the first 5 days of injection, the recommended initial target dosage was not reached due to the limitations of the temporary injection pump being used. Additionally, the brine sampling point was not ready yet due to operational conditions. Until October 31st, the only chemical injection point was at the upstream 2 phase location prior to the separator. Additional chemical injection at locations 2 and 3 was not carried out until November.

On October 7th, there were silica deposits on the separator level sensor which resulted in inaccurate separator level readings. Such deposits are typical when acid dosing is in use and in this case was attributed to not being able to dose the silica inhibitor at the recommended level.

Once correct inhibitor dosing had been achieved an inspection after a further 4 days of running showed strong improvement.

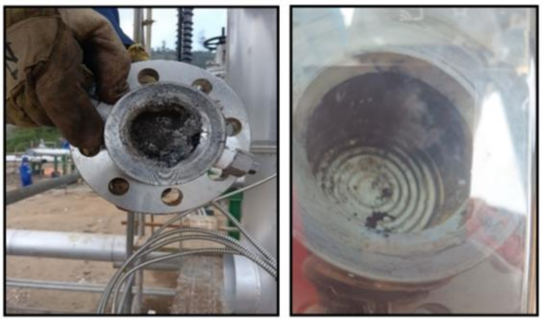


Figure 2: Comparison of level sensor before (left) and after (right) achieving the correct dosage.

4.2 November-December Period

During this period, all the inhibitor dosing systems were operating correctly to achieve the target dose rates and the KPIs targeted were achieved.

The % silica inhibition in this period was actually calculated at above 100% between the separator and AFT inlet. For example, in November, the average silica at the separator outlet was 708ppm and 756ppm at the AFT inlet. This may indicate some transient silica polymerization was occurring in the separator vessel that then depolymerizes on the way to the AFT. In contrast the average silica levels during October, when dosing was insufficient, were 734ppm at the separator outlet and 700ppm at the AFT inlet.

4.3 Scale Coupon Analysis

Coupons were placed in the After Separator, Inlet AFT, and Outlet AFT sample points. The after-separator coupon always showed the highest deposition rate as can be seen in Table 3 below and this did not change significantly during the trial period. SEM/XRF analysis of the deposit on the After Separator coupon (Figure. 6), showed a very high carbon content. This needs further investigation to determine the root cause.

The Outlet AFT scaling rate result was relatively high in the October period due to the dosing restrictions described above. However, once the dosing was correct in November and December the deposition rates were very low. The inlet AFT scaling rate data were not obtained in November and December due to mechanical damage of the injection port.

Table 3: Scale coupon summaries from October to December.

No.	Coupon Location	Scale Rate (mm/year)		
		October	November	December
1	After Separator	3.17	5.90	3,32
		3.41	5.83	4,20
2	Inlet AFT	1.72	-	0,01
		1.87	-	-
3	Outlet AFT	3.38	0.29	0,24
		3.74	0.25	0,16

Element	Wt %	At %
C K	60.18	67.67
N K	10.82	10.43
O K	22.86	19.30
NaK	00.61	00.36
AlK	00.32	00.16
SiK	01.56	00.75
S K	01.23	00.52
ClK	00.80	00.30
K K	00.24	00.08
CaK	00.97	00.33
FeK	00.43	00.10

Figure 3: The coupon is a carbon steel C1018 type with 14 days of insertion. Scale was also obtained and analyzed using SEM/XRF.

4.6 Brine Transfer Pump Discharge Pressure

The pressure during brine transfer from pond to pond (3km and uphill) remained constant at around 15 bar (the plant requires the pump discharge pressure to remain below 17 Bar). Pump discharge pressure was recorded on the plant DCS (See Figure 4).

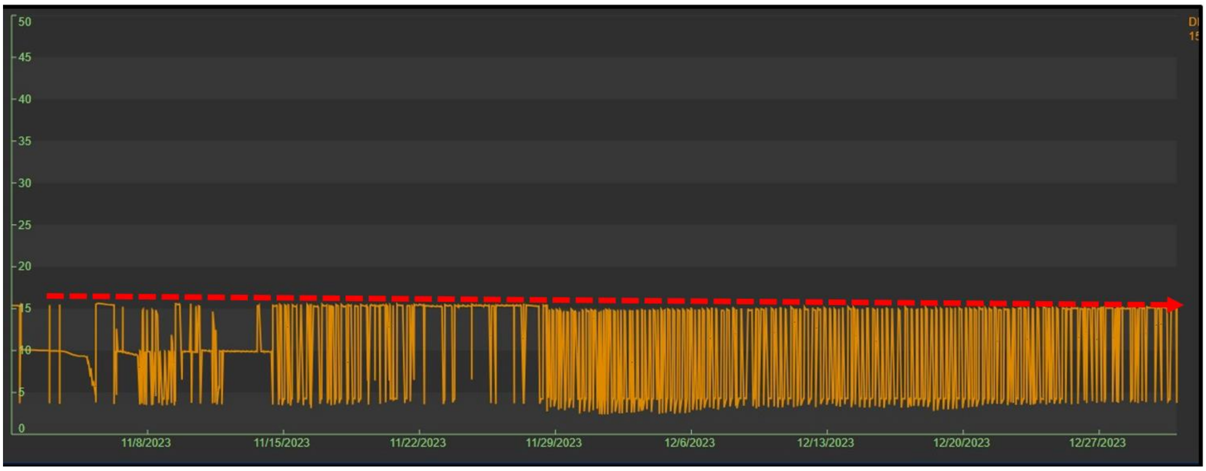


Figure 4: The stable pressure trend from the beginning until the end of trial

The pictures below show the transfer pump strainer as removed for inspection and cleaning every week. The picture on the left (October) shows the results of insufficient inhibitor dosage and no booster dosing of DPI-920. The picture on the right (November-December) corresponds to full and correct inhibitor dosage across the system.

Figure 5: Left side: strainer brine pump B without chemical treatment. Right side: Strainer brine pump B with 10ppm chemical treatment.

4.7 Dosage and % Inhibition

During the first 7 days in October KPI 1, KPI 2, and KPI 5 did not reach the inhibition target due to a delay in commissioning the dosing systems, however, when the #1 dosing system was finally up and running correctly the inhibitor was set at 80 ppm for 3 days. This initial large dose was used to maximize silica inhibition, and the results were used as a baseline.

After it was seen that the silica inhibition was > 95%, the dosage was reduced to 60 ppm for 2 days and then further reduced to 40 ppm. Other indicators were also monitored closely during the dosing optimization period.

Dosing into injection points #2 and #3 began in early November in order to provide deposition protection to areas further along the system. The chart below indicates the dose rates into each injection point.

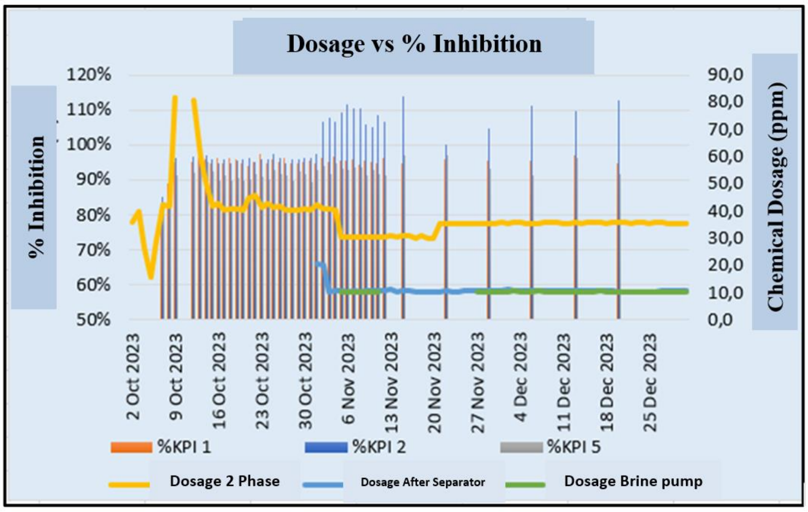


Figure 6: The dosage vs %inhibition graphic shows a stable result after correct dosing had been set up and optimized. KPI 1 is a comparison of % inhibition between baseline data (2 phases) and after separator. KPI 2 is the comparison between the after separator and the inlet AFT, while KPI 5 is the comparison of thermal pond outlet to inlet pond.

4.6 Cost Comparison with Acid Injection

GDE shared an internal report based on the 2023 economics study with projections on both DPI-920 and H_2SO_4 at the same well pad. The 98% H_2SO_4 consumption was 121 tonnes per year.

Operation and Maintenance (O&M) cost calculations were limited for studies based on laboratory analysis and the work plan and budgeting. Workover costs for the injection well were not included since many well pads feed into a single reinjection well.

The total product price, cost of maintenance, and losses during lost time production for the inhibitor usage are calculated based on the experience of the 3-month Solenis trial while the H_2SO_4 costs are based on the current work plan and budgeting.

The detail of the calculation is not shared in this paper but is summarized below in Figure 7.

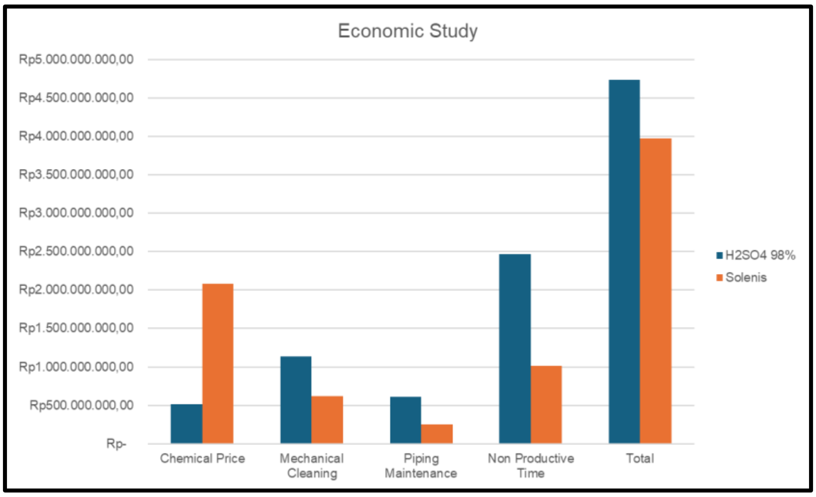


Figure 7: Chemical inhibitors are more efficient in the operational and maintenance process as they reduce the frequent silica cleaning costs, and pipe maintenance costs and reduce non-productive time.

Overall, the Solenis chemical inhibitor was more efficient in the O&M process since the reducing silica scale led to reduced cleaning costs and reduced downtime.

Based on the results of the projected total operational cost for 1 year, injection of DPI-920 would reduce the operational cost by close to 20% when compared with pH depression via addition of H_2SO_4.

5. CONCLUSION

After the 3-month trial, DPI-920 reduced the silica polymerization rate as measured by the Hach silica test. The scaling coupon analysis, also in conjunction with the brine analysis result, shows a low scaling rate and stable monomeric silica, respectively. The reduced scaling led to significant savings in downtime and operational costs.

The inhibitor has been used and compared with the traditional pH reduction method with a result of above 95% inhibition without causing any corrosion issues in the surface piping.

During the writing of this paper, GDE extended the contract for 1-year treatment with additional wells to be treated with Solenis proprietary anti-scalant chemicals.

ACKNOWLEDGMENT

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