RECOVERY OF REINJECTION WELL CAPACITY USING ONLINE DISSOLUTION

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Keywords: *online dissolution, silica scaling, reinjection well*

ABSTRACT

There are several methods available for cleaning a scaled-up geothermal well. These can either be mechanical or chemical. A typical chemical method is usually acidizing, which objectively is simply a tubular process or cleaning the vicinity of the wellbore to improve the well's productivity or injectivity.

Similar to acidizing, a novel method being explored by Nalco Water is Online Scale Dissolution targeted to dissolve scales in a reinjection well. This method involves injecting GEO991, a strong acid alternative, to the condensate or brine for a specified period of time to be able to dissolve scales in the wellbore; thus, improving well acceptance rate.

Prior to deploying the dissolution program in the field, scale samples from the reinjection well were subjected to dissolution tests using different dissolvers to determine the extent of dissolution that can be achieved and the suitable dissolver. From the results of the test, the most suitable dissolver is GEO991 with 100% scale dissolution affecting Si, As and Fe components. Online dissolution sidestream test was done to better understand and evaluate the product performance in a realistic and controlled environment. It was found that GEO991 can dissolve scales composed of 60-70% silica and 20% iron-bearing compound. Observations supporting this claim include the 5.32% reduction in the total weight of the scales, minimal silica crystal observation in the dosed line coupon, higher levels of silica and iron measured in the dosed line. No additional scaling was also confirmed as manifested by the following: constant flowrate maintained in the dosed line, a more stable line pressure and minimal to non-existent scaling in the pipe holder. The study gave us enough information and confidence for a commercial trial to proceed.

Full-scale commercial run happened in two phases on the target reinjection well. First phase lasted for 33 days improving the well acceptance rate from 3.74 kg/s (baseline) to 10.1 kg/s. The second phase of the trial lasted for 16 days and was able to reach 35 kg/s final well acceptance rate which was the original acceptance rate. The study was able to confirm that GEO991 dosing can be a favorable alternative to traditional rig and non-rig well intervention techniques based on the capacity recovery achieved, cost, ease of deployment and reduced to eliminated well downtime.

1. INTRODUCTION

Mineral scaling is attributed to the dissolved solids contained in deep geothermal fluids. There are several cases on how these dissolved solids form into scales. One case is due to the extraction of heat from the geothermal fluid. The conductive cooling of the fluid leads to deposition, since the solubility of most compounds is reduced at lower temperatures. Another case is the further concentration of these fluids, which also causes the scales to deposit because of super-saturation. In both cases considered, changes in physical and chemical properties can also occur as the fluids are extracted and these can cause mineral deposition (Brown, 2013).

There are several options available for cleaning a scaled-up geothermal well. These methods can either be mechanical or chemical. Usual mechanical means of clearing scales can be carried out either with or without a rig. A typical chemical method is acid washing, which objectively is simply tubular treatment or cleaning the vicinity of the wellbore (American Petroleum Institute, 2014). For both methods, the general objective is to improve the wells productivity or injectivity. Each method has its own different applicability, acceptance criteria and risks depending on thorough evaluation of a well.

Similar to acid washing, a novel method being explored by Nalco Water is Online Scale Dissolution targeted to dissolve scales in a reinjection well. This method involves injecting Nalco® GEO991, a dissolution chemical, to the brine or condensate for a specified duration to be able to dissolve scales in the wellbore; thus, improving the acceptance rate.

The main function of the active component is the formation of an effective complexing agent for the dissolution of silica, silicates, metal silicates and metal sulfides. This complexation reaction can be carried out at a pH of 3 and even above pH 6. Based on field evaluations, dissolution of metal sulfides and silicates is effective at lower pH ranges while dissolution of silica can happen even at high pH ranges. The product also functions as an inhibitor by depressing the pH of the system making it deficient of hydroxide ions which inhibits the polymerization of silica; at the same time, the product forms stable and dispersed complexes with silica/silicates to avoid agglomeration or reaction with other metals.

Although the product has a nitrogenous compound that acts as a corrosion inhibitor, supplementary inhibitors such as imidazolines and quaternary amines can be used to further minimize the corrosive potential.

The amount of acid salts available in the system is dependent on the dosage of the product. In systems where in the product is being fed through a brine that contains significant amount of silica, higher dosage can be expected in order to compensate for the amount of complexing agent needed to dissolve and at the same time inhibit incoming silica particles. To maximize the potential of the product, it is recommended that the stream that will carry it downstream should have minimal or no silicon-containing components.

Temperature also plays a critical role, theoretically, the complexation reaction of the product with silicon-containing scales is faster at elevated temperatures.

The evaluation of the chemical happened in three phases, specifically laboratory dissolution study, field sidestream test and actual commercial dosing. Stepwise deployment was done in order to get confidence that the proposed dissolution program will work on an actual field setting. Laboratory dissolution test subjects the scale samples to different dissolvers including GEO991. This is to determine the best dissolution chemical to use for a specific scale composition. The sidestream test involved a small setup that was used to further understand the performance of the chemical and its corrosion potential on a more controlled and operationally non-invasive way. This involved getting a portion of the brine and treating it, as it goes through the rest of the setup. This type of test was exploratory in nature and helped gain better understanding on the kinetics and performance of the product without affecting the operability of the actual well. The aim of the test was to establish baseline data to show that the chemical can dissolve existing scales by correlating it with flow improvement and corrosion rate to optimize dosing when applied in the actual field.

The full commercial run was divided into two phases, the first one happened August 2018 and the second phase started March, 2019. The goal of the commercial run was to achieve the target flowrate of 30-35 kg/s based on a 100-day chemical consumption plan.

2. LABORATORY DISSOLUTION TEST

Prior to the deployment of dosing program in the actual site, several scale samples with varying compositions were used to test the dissolution performance of GEO991. Two rounds of laboratory dissolution tests were done, one was for the scale samples representative of the sidestream test and the second one was for the sample representative of the target well. The samples have silica levels ranging from 50-60% w/w.

Elemental analysis by x-ray fluorescence (XRF) was done on two scale samples representative of the sidestream test scale to determine the identity of the scales. Figures 1 shows the characterization of these two samples, both from reinjection solid traps. Both samples show that the major components are silica and iron-containing compound. The result of the XRF agrees with the previous data from the customer, which indicated that the major scaling compounds present were amorphous silica and iron sulfide.

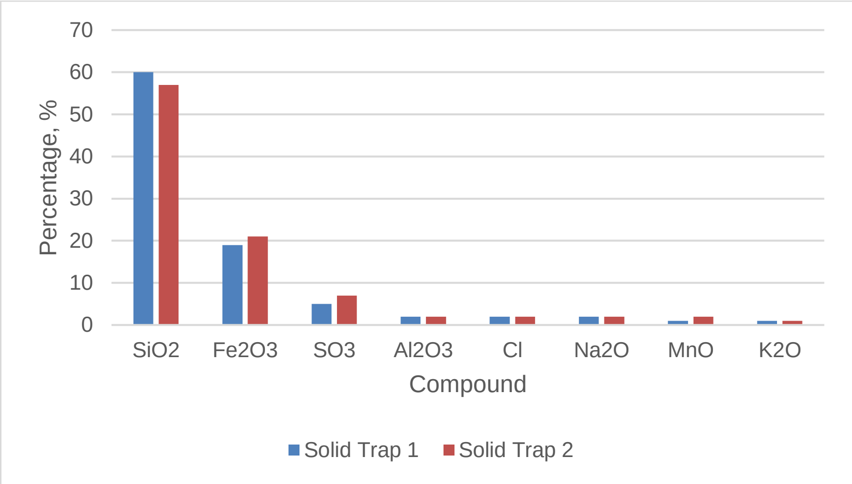

Figure 1. Elemental analysis using XRF of the scale samples.

Prior to the commencement of the trial, a laboratory dissolution test was done to determine the compatibility of the dissolution product (GEO991) and performance against other potential dissolvers particularly HCl and chelant. Scale samples were dried at 140°C for 4 hours to remove inherent moisture. One gram of sample was placed on each test bottle where 10% v/v of dissolvers were added. The test bottles were then placed on an orbital shaker at 200 rpm, 60°C for 24 hours. Final weights were measured, and the filtrate was sent for ICP analysis to determine percent dissolution by component.

The second dissolution test was done on the actual scale sample from the target well. Samples were sent to Nalco Singapore Analytical lab for XRF analysis to get the percent composition of the scales. This will help in quantifying the dissolution performance of the product on a composition-level basis. The table below summarizes the result of the XRF for the scale sample:

Table 1. Scale composition of the actual target RI well.

Component	**Weight Percentage (%)**
Silicon (SiO_2)	55
Arsenic (As_2O_3)	15
Iron (Fe_2O_3)	12
Sulfur (SO_3)	2
Aluminum (Al_2O_3)	1
Phosphorus (P_2O_5)	1

Scale samples from the actual well were subjected to dissolution tests using different dissolvers to determine the extent of dissolution that can be achieved and the suitable dissolver. From the results of the test, the most suitable dissolver is GEO991 with 100% scale dissolution affecting Si, while also affecting As and Fe components.

Table 2. Dissolution performance of different chemistries

Sample	Total Dissolution (%)	Silica Dissolution (%)	Iron Dissolution (%)	Arsenic Dissolution (%)
GEO991	76	100	34	29
Chelant (caustic solution)	26	10	12	52
HCl	59	60	34	46

2. ONLINE DISSOLUTION SIDESTREAM TEST

An online dissolution side-stream test was carried out to evaluate GEO991 further. The test was carried out in a more controlled and operationally non-invasive way by getting part of the brine flow from the main line and letting it run through the system; thus, mimicking downhole conditions using scaled alvenius pipes as the wellbore. Several parameters were measured throughout the trial to further understand the dissolution performance of the product and its corresponding corrosion potential. These parameters are line pH, flowrate, SiO_2 levels, iron levels, and corrosion rates through probes and coupons.

2.1 Test Setup

The setup was constructed based on the schematics on Figure 2. A 1-inch branchline supplied the needed brine for the sidestream test. Each line had its own scaled up alvenius pipe which mimicked a scaled reinjection wellbore. The undosed line served as a control to account for erosion and corrosion contributed by the untreated brine. The dosed and undosed lines both had probes and coupons for corrosion monitoring and catchment basin to monitor the flowrate. Sampling points were installed for in situ monitoring of pH, Fe and SiO2. Actual field setup is shown on Figure 3.

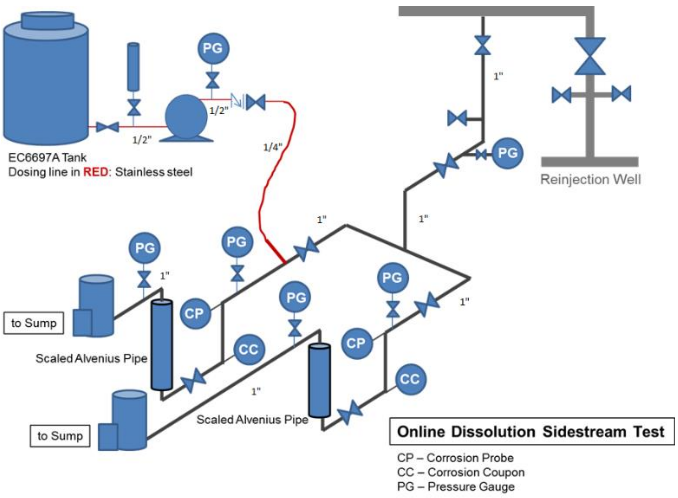

Figure 2. Schematic diagram of online dissolution sidestream setup

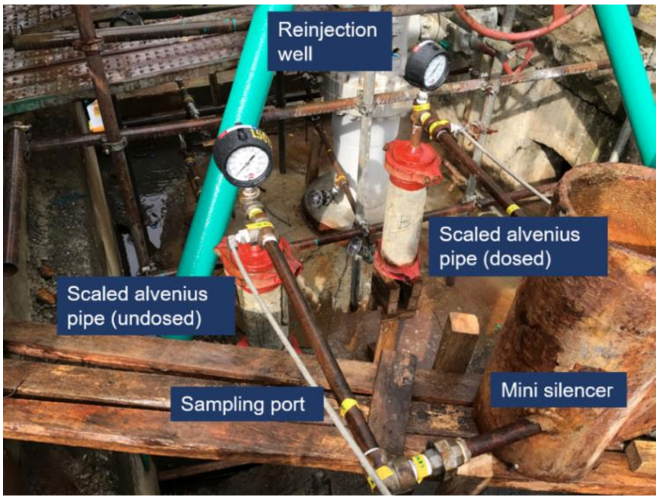

Figure 3. Downstream setup after the scaled up alvenius line

2.2 Dosing Schedule and Methodology

The dosing schedule was patterned on the previous commercial trial in the US conducted by Gill et al. (2017). The commercial trial was done for 48 hours with 4.5 to 6.25% of the whole duration allotted for 100 ppm, additional 4.5 to 6.25% for 50 ppm and the rest (87.5 - 91%) for the 20 ppm dosing. Given the nature of the scaled alvenius pipes (see Figure 5), it was decided to extend the dosing schedule from 2 days (48 hours) to 6 days but still maintaining the percentage of each dosage level. The dosing schedule used for the trial was 100 ppm for 8 hours, 50 ppm for 8 hours and 20 ppm for 120 hours. During the course of the trial, the 50 ppm was further extended by 5 hours to reinforce brine catchment for flow calibration. The actual dosing schedule followed was 100 ppm for 8 hours, 50 ppm for 13 hours and 20 ppm for 123 hours.

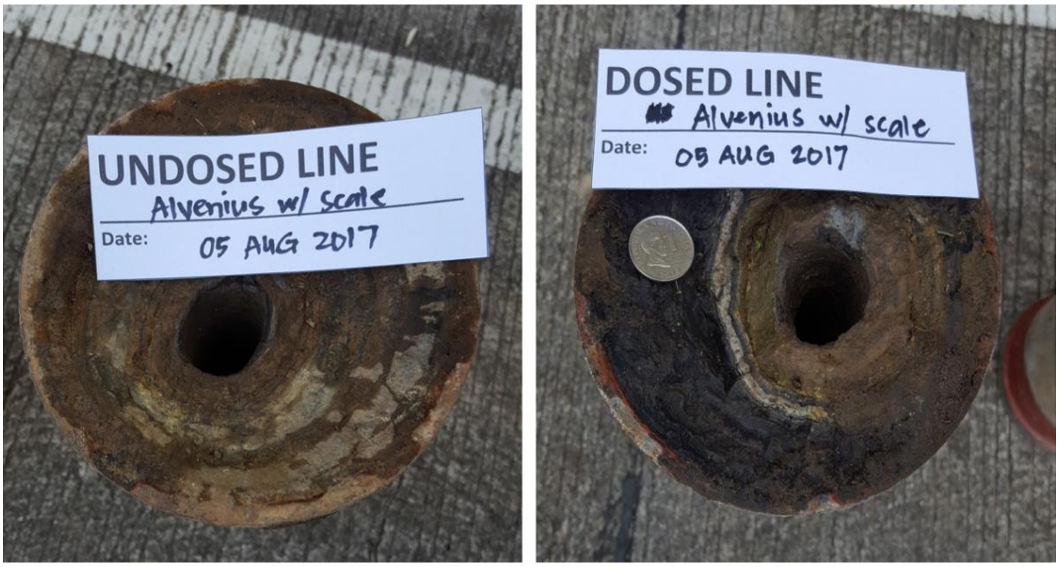

Figure 4. Pre-trial state of the dosed and undosed alvenius pipes

Initially, a brine titration was done to determine the amount of product needed to bring down the pH to 4.5-4.9. This gave the system enough acidity to dissolve iron-bearing scales. For silica, the product could dissolve at any pH even if it was higher or lower than the targeted range. The baseline dosing considered for the titration test were 100, 50 and 20 ppm respectively.

The acceptable pH level for the customer was 4 but 3 could be tolerated. This meant that they were still willing to operate the well at this condition and still would get an acceptable corrosion rate of 0.12 mm/year. Using the baseline dosage of 100 ppm as a reference, it showed that the line pH went below 4 but still above the operable limit of 3. Given that the high dosages (100 and 50 ppm respectively) were applied for a short period of time, it was still manageable and acceptable to follow the desired dosing schedule.

Prior to trial commencement, initial weight of the coupons and scaled alvenius pipes were measured. Flow and dosing calibration were done to ensure that the pump delivered the desired line concentration. Baseline water sampling was also conducted for comparison with the chemistries of the dosed and undosed lines.

During the trial, in situ analyses of pH, iron and silica were conducted for both dosed and undosed lines. These measured parameters helped to give an indication that the product was indeed dissolving silica and metal sulfides. Within each dosing level, brine flowrate for each line was recorded and corresponding dosing rate was recalibrated.

After the sidestream test, the corrosion coupons were weighed to get the overall corrosion rate of the system based on the dosing plan. The scaled alvenius pipes for both lines were also weighed to get the percentage of the scales dissolved.

2.3 Sidestream Test Results

The alvenius pipes used to mimic the wellbore were 80-90% scaled up and evident characteristics of the scaling present were compact, rock-like and not easily chipped off. This can be regarded as severe scaling due almost complete blockage and difficulty level of scale removal. The dissolution chemical had limited contact with the scaled portion of the pipe. Since the product was incorporated with brine, the product reacted only with the exposed portion of the clearance, upstream and downstream area of the bases. The illustration on Figure 5 shows evidence of dissolution for both the upstream and downstream sides.

Figure 5. Physical manifestation of dissolution in the dosed line (A) upstream (B) downstream.

Based on the dosing schedule used, the product could dissolve a portion of the exposed scales given enough contact time. The upstream portion showed an increased dissolved region and this could be attributed to pressurization and initial chemical contact.

After complete drying of the alvenius pipes, the final weight for both the dosed and undosed line were measured and the % weight reduction was calculated. Table 2 shows the weight data of both pipes.

Table 2. Initial and final weights of the pipes and calculated % reduction. (Source: Gica, 2017)

Line	Initial Weight, kg	Final Weight, kg	% Reduction
Dosed	16.18	15.32	5.32
Undosed	15.26	15.16	0.66

The undosed line also incurred weight loss which may be attributed to pressurized brine flow and saturation along the exposed regions.

2.3.1 Monitoring of Flowrate and pH

For the dosing plan considered, the critical part was the dosing of 100 and 50 ppm of product. At these dosing conditions, it was expected that the pH values will be low, which in turn, corrosion rates were expected to be high.. Flowrate was also measured because it was a straightforward indicator of product effectivity. An improvement in the flowrate of the dosed line might already be attributed to dissolution of exposed scales; thus, opening the restriction of the pipe. Figure 8 shows the brine flowrate for both the dosed and undosed line.

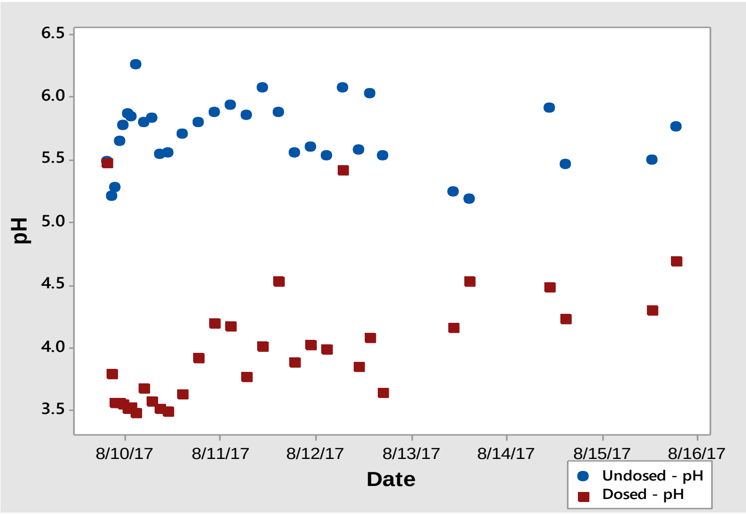

Figure 6. pH levels of dosed and undosed lines

The pH levels of the dosed line during the 100 and 50 ppm dosing were at 3.5. This was below the optimum pH level of 4.5 but above the operationally-acceptable limit of 3.0. The critical dosing period should be monitored because at this point, corrosion rates were expected to be high. The pH of the system upon dosing, however, still depended on the initial pH of the untreated brine. A lower starting pH would have different corrosion rates compared to a near neutral system.

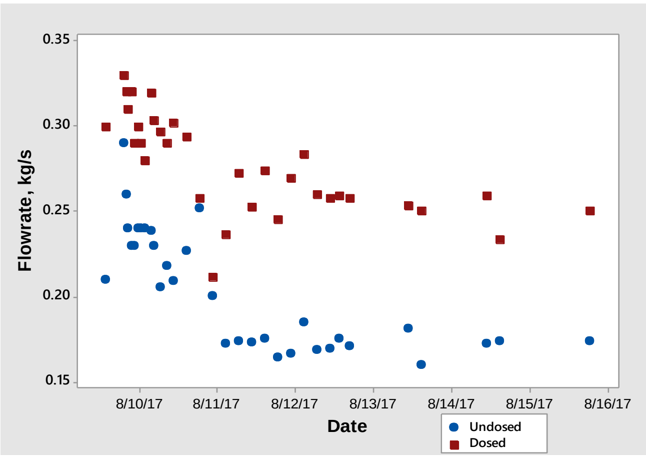

Figure 7. Brine flowrate for both the dosed and undosed lines.

Theoretically, an increasing trend for the dosed line should be observed since dissolution on some regions were observed. The measurement was not able to get the desired trend due to operational constraints. There were times where the brine flowrate in the system was changing and the team was not able to account how much brine was added or decreased in the system. A factor also was incomplete catchment of the brine in the mini-silencer which resulted to decreased flowrate during measurement. Upon inspection of the scaled up, moisture saturation was also observed for both pipes which may also be a contributing factor.

2.3.2 Corrosion Measurement and Coupon Megascopic Analysis

Corrosion probes were used to measure the corrosion rates during the whole duration of the trial for both the dosed and undosed lines. As expected, higher corrosion rates were observed in dosed line at 100 to 50 ppm dosing. Figure 8 shows the observed corrosion rates at varying dosing levels.

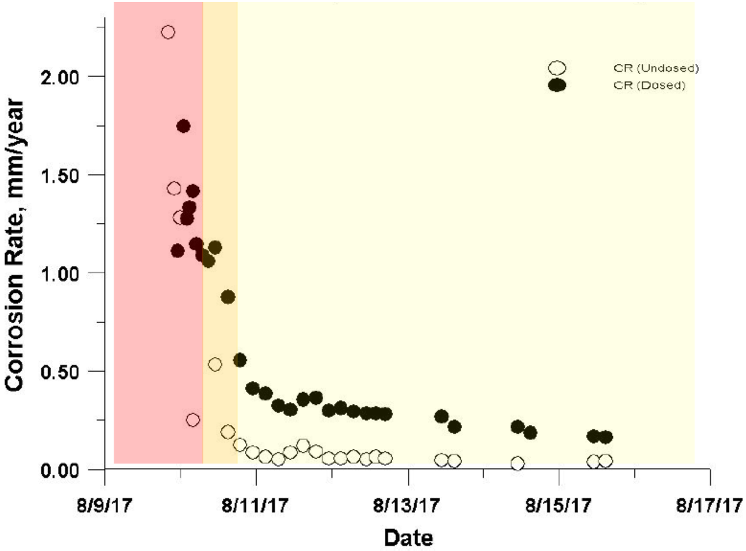

Figure 8. Corrosion rates during the trial with reference to effective concentration of the dosed line (Gica, 2017)

The baseline corrosion rate (undosed line) is almost constant at 0.10 mm/yr. For 100 ppm down to 50 ppm, initial corrosion rate was 1.16 mm/yr then eventually went down to 0.36 mm/yr upon reduction of dosage to 20 ppm and was held constant throughout the trial. The achieved average corrosion rate was higher compared to acceptable corrosion rate of 0.12 mm/yr. For the corrosion coupon, the calculated metal loss for both the dosed and undosed lines were 1.0042 mm/yr and 0.8194 mm/yr respectively. This captured the overall corrosion rate of the trial and both lines having almost comparable corrosion rates.

Megascopic analysis of the coupons further explained the activity of the treated and untreated brine on K55 carbon steel casing. For the undosed line, clay-sized silica scales and corrosion products in the form of magnetite, hematite/goethite, bornite and iron sulfides were observed on the surface of the coupon. Bigger silica crystals were more frequently observed around or near the pits. For the dosed line, majority of the components were corrosion products. Large crystals of silica were rarely spotted compared to the undosed line surface (Gica, 2017). This confirmed the assumption that dosing the product online was also a way of controlling silica polymerization by pH modification. Acid dosing can delay silica polymerization and deposition in reinjection wells can be minimized (Mroczek et al., 2010). Figure 11 also shows the minimal to almost non-existent scale deposition on the dosed line pipe holder compared to that of the undosed line which confirmed that the dosing did not contribute to further silica scaling in the system.

Figure 9. Scaling in the pipe holder for the dosed (A) and undosed (B) lines.

2.3.3 Silica and Iron Monitoring

Silica and iron levels were measured on site to monitor the dissolution performance of the product. Theoretically, higher levels of silica should be observed in the dosed line to indicate that dissolution is happening. Iron levels in the dosed line were also expected to be higher compared to the undosed line because the scale characterization shows an Fe-bearing component, which can be dissolved at lower pH, and possible line corrosion. Figures 10 and 11 show the trend for silica and iron levels respectively.

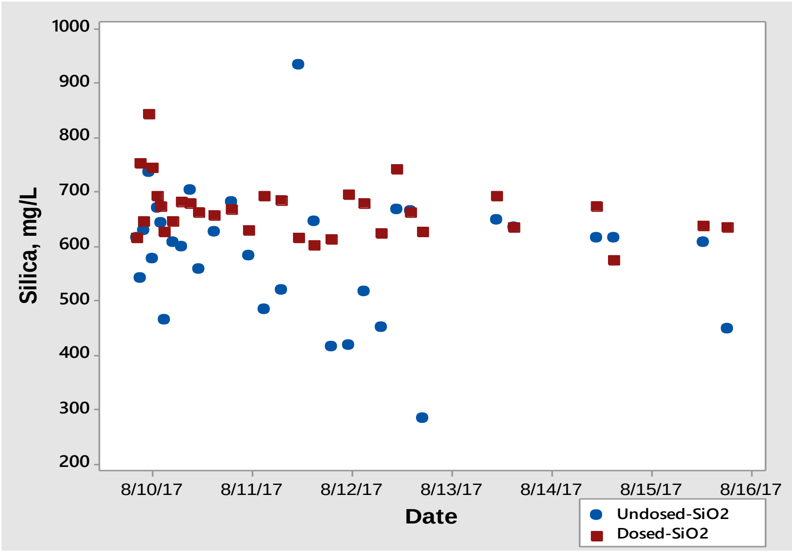

Figure 10. Silica levels measured on-site.

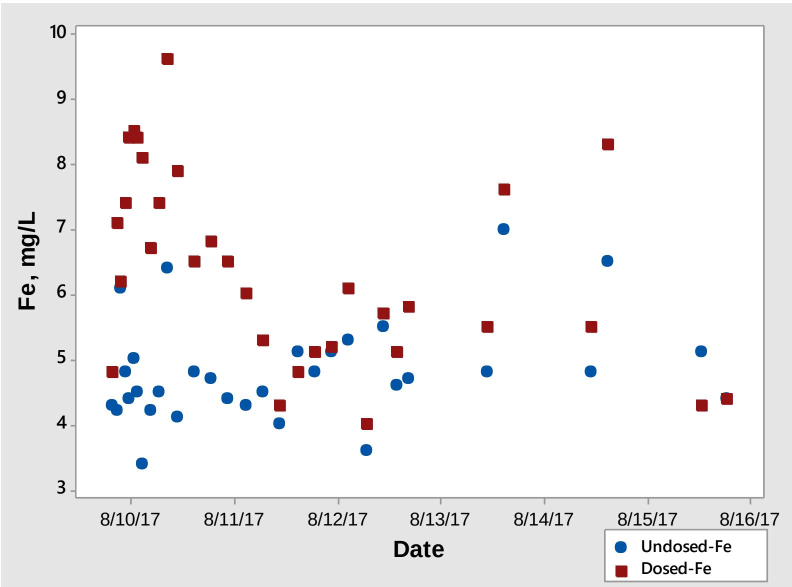

Figure 11. Iron levels measured on-site

Higher silica levels were observed in the dosed line which likely indicated that dissolution of silica scale happened. The silica seemed to be stable also compared to the readings in the undosed line. This showed that kinetics of silica polymerization was controlled in the dosed line. Iron levels observed were also higher as expected, this can be attributed to dissolution of iron-bearing scales and corrosion products. At the critical dosing level of 100 down to 50 ppm, higher iron levels were observed due to low pH. Iron-bearing scales were more soluble at lower pH and more corrosion products were likely present in the system at this pH level.

3. ACTUAL FIELD APPLICATION

The laboratory and sidestream tests gave us enough information and confidence for a commercial trial to proceed. Since improvement on the well acceptance rate is the primary criteria of success, the previous study was not able to properly quantify improvement in flowrate. To fully quantify the effectivity of the online dissolution method, an actual field application was done on the target reinjection well with a low initial acceptance rate due to scaling.

Initial commercial run on target reinjection well commenced last August to September 2018. The target well was used for dumped brine (collected from the sump). The existing well flowrate prior to online dissolution is at 3.74 kg/s with 0.11 MPag wellhead pressure (WHP). After 33 days of dosing, well flowrate increased to 10.1 kg/s with 0.10 MPag WHP.

For this particular well, power plant condensates were used as carrier fluid for the dissolver. This was different from the past online dissolution field trials conducted where the carrier fluid used was geothermal brine. The use of a fluid devoid of silica may be advantageous because the dissolver will focus on existing deposits instead of getting competing reaction from the silica content of the brine. Aside from the carrier fluid, the dosing was also extended compared to the 10-day dosing strategy implemented for the previous wells following the Hudson Ranch example as explained by Gill et al. (2017)

The succeeding graph shows the historical well flowrates for target well:

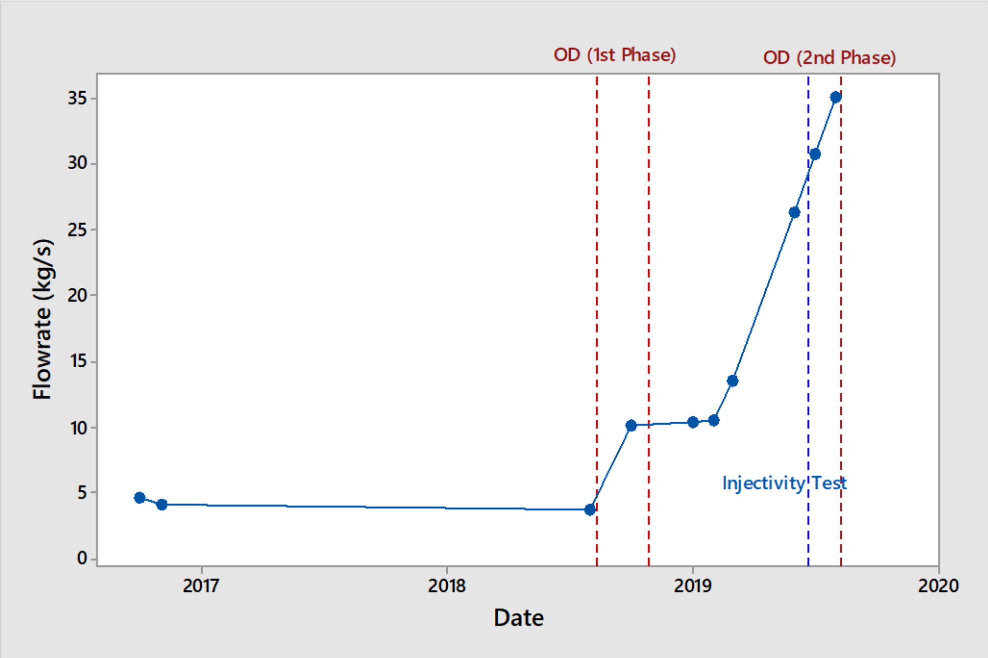

Figure 12. Well flowrates before and after phases 1 and 2 of online dissolution

Figure 10. Well flowrates before and after phases 1 and 2 of online dissolution

The commercial run was further extended from June 2019 to August 2019. The target was to reach 30-35 kg/s which was the historical reinjection capacity (RICAP) of the well. The baseline flowrate was at 13.5 kg/s (1.0 MPag) where the well was continuously utilized for power plant condensates. Prior to the second phase of online dissolution, injectivity test was conducted which resulted in a sudden increase in RICAP of the well. From 13.5 kg/s, the pre-online dissolution baseline was adjusted to 26.30 kg/s. The second phase of the dissolution project was able to achieve 35 kg/s well flowrate after consuming three totes of the product.

Since the product has the capacity to increase the porosity of the scales, it was able to weaken the structure of the scales thus introducing cleavage points. The sudden increase in the flowrate may be attributed to the disintegration of scales upon subjecting the well to high pressure and high-water flowrates during the injectivity test. Online dissolution with total injection of 5 totes Geo 991 resulted to net improvement of 15.36 kg/s in the target well and reaching the target of 35 kg/s.

Table 4. Summary of parameters for RI well online dissolution

Parameter	RI Well, Phase 1 *Aug 2018-Sept 2018*	RI Well, Phase 2 *July 2019-Aug 2019*
Previous Well Utilization	Dumped brine	Power plant condensates
Fluid Used during OD	Power plant condensates	Power plant condensates
Maintaining pH	3.0 - 3.5	3.0 - 3.5
Line Conc, ppm	90-100	100-130
Pre-OD WF, kg/s	3.74	26
Post OD WF, kg/s	10.1	35
WF increase, kg/s	6.36	9
Pre-OD WHP, Mpag	0.11	0.10
Post- OD WHP, Mpag	0.10	0.10
% WHP improvement	9.09%	-
No of totes	**2**	**3**
Dosing days	**33 days**	**16 days**

4. CONCLUSIONS

An online dissolution side-stream test was carried out to better understand and evaluate the product performance in a realistic and controlled environment. The trial helped in evaluating the dissolution performance and corrosion potential of the product which will be critical for a full scale commercial test. It was found that Nalco® GEO991 can dissolve scales composed of 60-70% silica and 20% iron-bearing compound. Observations supporting this claim include the 5.32% reduction in the total weight of the scales, minimal silica crystal observation in the dosed line coupon, , higher levels of silica and iron measured in the dosed line. No additional scaling was also confirmed as manifested by the following: Constant flowrate maintained in the dosed line, a more stable line pressure and minimal to non-existent scaling in the pipe holder.

The study gave us enough information and confidence for a commercial trial to proceed. Since injectivity or well acceptance rate is the primary criteria of success, the study was not able to properly quantify improvement in flowrate. The best way to quantify this is through a full scale commercial trial.

Online scale dissolution commercial run in the target RI well has proven that this new technology can be a replacement to the traditional mechanical or chemical means of regaining lost reinjection capacity. The use of GEO991, coupled with injectivity testing, was able to yield a final flowrate of approximately 35 kg/s from the starting flowrate of 4 kg/s. The use of power plant condensates as carrier fluid and the continuous utilization for the same fluid helped in maintaining better flowrates since there is no further deposition of silica downhole.The method is worth considering for declining wells with scale composition similar to the subject RI well and for those wells that showed promising laboratory dissolution test results.

Initial economic evaluation showed that implementing GEO991 program on this well can save up to 50% of conventional acidizing costs. The cost comparison depends on the amount of the product needed to increase the flowrate up to the target level which vary from well to well.

ACKNOWLEDGEMENTS

The authors would like to thank Energy Development Corporation and Nalco Water for the support and permission to submit this paper.

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