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Removal of Anhydrite and Mg-Silicate Scales from Production Wells Using Chemical Agents at the Mori Geothermal Field in Hokkaido, Japan: An Application of Chemical Well Stimulation

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ABSTRACT

Well stimulation, which enhances permeability, is an important technique in the creation of Engineered Geothermal Systems (EGS). In addition to physical stimulation such as hydrofracturing, chemical stimulation has been used at several EGS fields. In addition to conventional mineral acids, chelating agents and alkaline solutions have been studied and employed to dissolve calcium and silica minerals without significant casing corrosion. We tested the notion that this chemical stimulation technique was applicable to the removal of anhydrite and Mg-silicate deposits as a replacement for costly mechanical workovers.

We conducted two scale removal operations using chelating and alkaline agents at the Mori geothermal field. Two distinct scale minerals, anhydrite and Mg-silicate, were observed in two different production wells. The latter scale consists of crystalline and amorphous structures. We confirmed that the chelating and alkaline solutions not only dissolved anhydrite and Mg-silicate scales but caused them to spall into particles and powders in the laboratory prior to the stimulation on site. The spalled scale fragments can be readily ejected from the wellbore during production.

We injected a chelating agent and alkaline solutions into the wells in July and November, 2008. Combined with successive production, the majority of scale was removed and the treated wells showed improved productivity.

1. INTRODUCTION

Geothermal brines have the potential to produce scale minerals through such processes as boiling and fluid mixing in the wellbore and piping. Because scale deposits in producers reduce their productivity, removal and prevention of the scale deposits are important tasks in the management of steam production. In the Mori geothermal field (Hokkaido, Japan), three kinds of scale minerals, calcite, anhydrite, and Mg-silicate, are found in the producers. Deposition of calcite and anhydrite has been prevented by injecting a scale inhibitor, a polyacrylate solution, through downhole tubing inserted into the producers. In the producer NF-12, however, anhydrite precipitates below the depth where the scale inhibitor is delivered. In addition, Mg-silicate deposits in another producer NF-1 even though the scale inhibitor is used, which suggests that the polyacrylate solution does not prevent Mg-silicate deposition. These scale deposits found in NF-12 and NF-1 decreased the productivity of the producers, and hence scale removal was required.

One conventional method to remove scale deposits is a mechanical workover, which is costly and takes a relatively extended period of time. Chemical stimulation, in which the scale minerals are dissolved by chemical agents, is less costly and can be completed in a short time, and we thus considered chemical stimulation in the field. The most popular chemical agents used in the chemical stimulation are mineral acids, e.g., hydrogen chloride (HCl) and hydrogen fluoride (HF). These acids, however, could not be used because of their corrosive properties, and they are less likely to effectively dissolve anhydrite.

Other than the mineral acids, chelating agents and alkali can be used for chemical stimulation. Their solutions are alkaline and much less corrosive than the mineral acids, which means they can be used in a wellbore. The chelating agents have been used to dissolve carbonate and sulfate including anhydrite in oil fields (e.g., Crabtree et al., 1999 and Moghadasi et al., 2007). Application of the chelating agents to EGS fields has been studied by Mella et al. (2006), Rose et al. (2007), and Nami et al. (2008). Two kinds of chelating agents, ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA), were tested in their studies, and we selected sodium salt of EDTA ($EDTA•4Na•4H_2O$) to dissolve anhydrite in NF-12.

Although it is well known that alkaline solution dissolves silica minerals, it hardly dissolves crystalline Mg-silicate (e.g., clay minerals). The Mg-silicate scale in NF-1 consists of crystalline and amorphous structures based on X-ray diffraction analysis. Hence we expected that the alkaline solution would dissolve the amorphous Mg-silicate and we employed sodium hydroxide (NaOH) for the chemical stimulation for NF-1.

This paper describes the result of a simple experiment in which scale samples reacted with chemical agents in beakers, and demonstrates the results of chemical stimulation of the producers NF-12 and NF-1.

2. SCALE DEPOSITS IN PRODUCERS

2.1 Producer NF-12

Figure 1 shows the location of scale deposition within NF-12 in a schematic cross section. Airlift piping and downhole tubing, which delivered the scale inhibitor, were inserted into the well. The inhibitor had been minimizing the deposition of calcite and anhydrite above the injection point (2,057 m MD). Meanwhile, anhydrite was presumed to precipitate below the injection point of the inhibitor because

(1) a temperature logging tool whose diameter was 32 mm stopped descending close to the injection depth at 2,058 m MD (August, 2007), and (2) anhydrite was identified in the solid residue of NF-12 brines by X-ray diffraction analysis. After this log, the injection point was set to a shallower depth (2,048 m MD), thereby allowing the anhydrite scale to develop up to the depth before the scale removal operation.

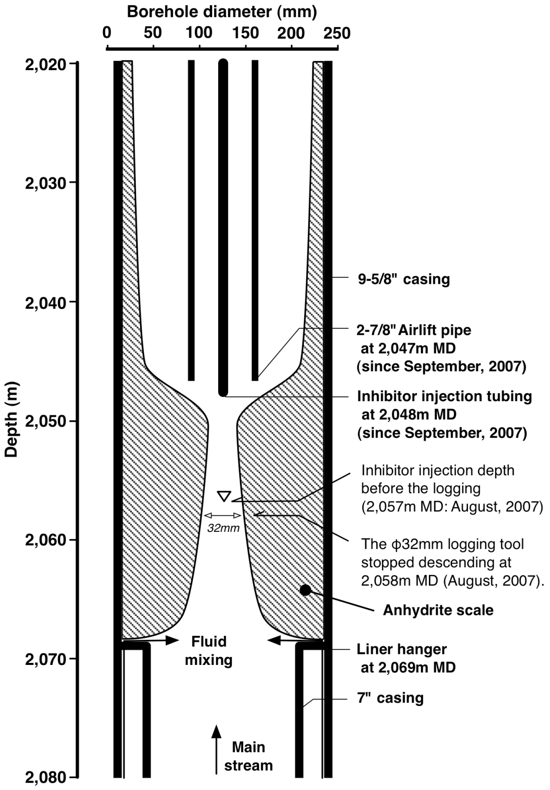

Figure 1: Schematic cross section of NF-12 showing casing, airlift piping, inhibitor injection tubing, and anhydrite scale deposits. The deposits before chemical stimulation were estimated to occur between 2,048 and 2,069 m MD.

We assume that the anhydrite precipitates through a process in which the produced fluid in the main stream mixes with a fluid entering from the aperture on top of the liner hanger at 2,069 m MD. This inflow is thought to ascend through the annular space between the 9-5/8" and 7" casing strings at depth. We then estimated that the range of the scale deposit was 2,048 to 2,069 m MD, and its volume was about 0.4 m^3.

2.2 Producer NF-1

Figure 2 shows the location of scale deposition within NF-1 in a schematic cross section. The scale mineral was identified as Mg-silicate, which was composed of crystalline and amorphous structures based on X-ray diffraction analysis of rock samples ejected from NF-1. The observations of the occurrence of Mg-silicate scale in several producers in the field show that the scale tends to deposit mainly at flash points, and hence we deduced that the scale in NF-1 deposited at 420 m MD where the flash point was found from a previous log.

3. SIMPLE EXPERIMENT

We conducted a simple experiment in order to observe the changes in shape and appearance of scale samples caused by reactions with EDTA and alkaline solutions. We assumed that when the samples partially dissolved in the solutions, the chemical agents could not fully react with the targeted scales due to inadequate reactive surface area and reaction rate even if sufficient amounts of the chemical agents were used in the well stimulation.

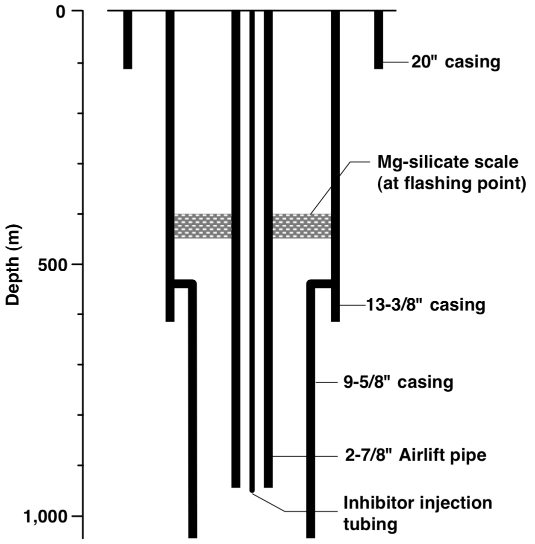

Figure 2: Schematic cross section of NF-1 showing casing, airlift piping, inhibitor injection tubing, and Mg-silicate scale deposits. The deposits were estimated to occur at 420 m MD (flash point).

Two samples of anhydrite grain samples weighing 3 g each were put in 80 ml of a 0.16 M EDTA solution and 80 ml of distilled water, respectively, and two samples of Mg-silicate grain samples weighing 3 g each were put in 40 ml of 2 M NaOH solution and 40 ml of distilled water, respectively. The solutions were then stirred by magnetic stirrers at room temperature. Figures 3 and 4 show the samples treated with the chelating and alkaline solutions, respectively. Fine particles and powders were produced by the reaction with the chemicals. We then concluded that the chelating and alkaline solution not only dissolved but also spalled anhydrite and Mg-silicate scales into particles and powders, which can be easily ejected from the producers during production. We also observed that stirring the solutions accelerated spalling of the samples. This spalling effect enhances the effective chemical stimulation beyond the effect of mineral dissolution alone.

4. CHEMICAL STIMULATION OPERATION

4.1 Producer NF-12

Chemical stimulation for NF-12 was conducted from the 16th to the 20th of November 2008. For this stimulation, the sodium salt of EDTA was used to dissolve anhydrite scale in the wellbore (Table 1). The amount of the anhydrite scale was estimated to be 1,190 kg; therefore 4,000 kg of $EDTA•4Na•4H_2O$ was prepared on the assumption that one mole of EDTA dissolves one mole of anhydrite (Bodine Jr. and Fellnard, 1973). Because the chelating ability of EDTA solutions increases with pH (Fredd and Fogler, 1998), we added NaOH to the EDTA solution and raised the pH to more than 12. The EDTA solution was delivered through a 2-7/8" pipe to the depth of 2,030 m MD, which was shallower than the top of the scale deposit by 19 m. The EDTA solution of 0.5−1 wt% (ca. 0.011 mol/l − 0.022 mol/l) was continuously injected at the rates of 5−20 kl/h during the day. We expected the continuous injection to create a flow on the surface of the scale deposit and to accelerate the spalling process as seen in the previous experiment in which the stirring of the chemical solutions was very effective for the spalling of the scales.

Table 1: Conditions of the chemical stimulation for NF-12 and NF-1.

Target	Solution	Concentrations	
Producer NF-12 Anhydrite	EDTA solution 445 kl	EDTA NaOH pH	0.022 - 0.11 mol/l 0.01 mol/l >12
Producer NF-1 Mg-silicate	Alkaline solution 600 kl	NaOH pH	0.05 mol/l 12 - 13

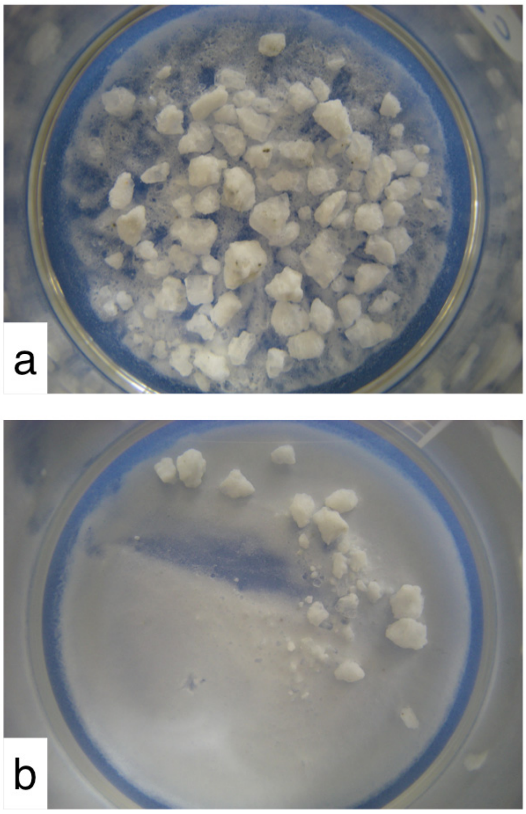

Figure 3: Anhydrite samples, initially weighing 3 g each, reacted with 0.16 M EDTA solution and distilled water. The sample reacted with the EDTA solution (b) was more dissolved and spalled into powders than the sample reacted with distilled water (a).

The injection system used a noisy pump, which was required to stop during the night, and 10 kl of a somewhat concentrated EDTA solution (2 wt%) was injected at the end of the day's operation. We expected the anhydrite scale to be dissolved more in such a concentrated solution under static conditions. For the final injection batch on the 20th of November, a 5 wt% (0.11 mol/l) solution was used, and the well was shut in for three days, followed by flushing with surface water. The total volume of the EDTA solutions was 445 kl.

4.2 Producer NF-1

Chemical stimulation for NF-1 was conducted from the 28th to the 30th of July 2008. A 0.2 wt% (0.05 mol/l) NaOH solution was used to treat Mg-silicate deposits (Table 1). The pH of the solution was measured to be 12−13. A total of 600 kl of the solution was continuously injected from the wellhead at rates of 13−15 kl/h, followed by flushing with surface water.

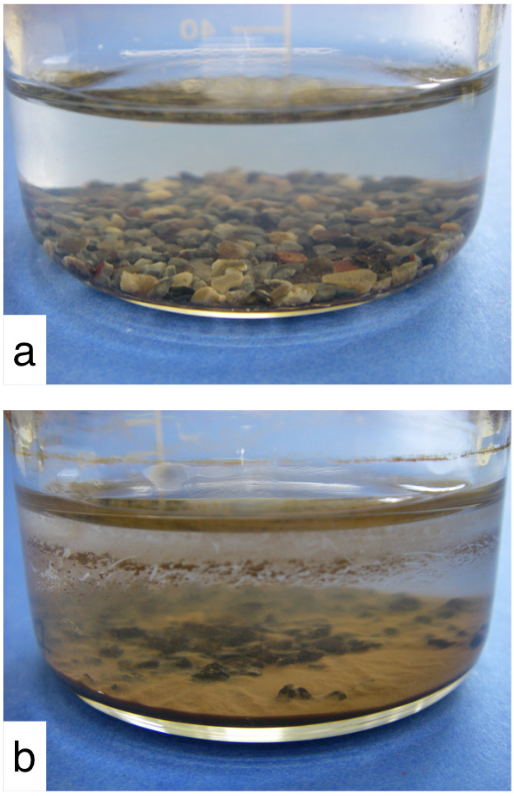

Figure 4: Mg-silicate samples, initially weighing 3 g each, reacted with 2 M NaOH solution and distilled water. The sample reacted with the NaOH solution (b) was more spalled into powders than the sample reacted with distilled water (a).

5. RESULTS AND DISCUSSION

5.1 Producer NF-12

The effect of the chemical stimulation on the productivity of NF-12 was evaluated by a caliper log and the monitoring of the wellhead pressure and production flowrate. Figure 5 shows the result of the caliper log conducted before the initiation of discharge of NF-12, and a schematic image of the residual scale deposits. The caliper log revealed that the diameters of the depth from 2,048 to 2,069 m MD were 190 to 80 mm, although the diameter of that depth had been estimated to be less than 32 mm by the previous logging. This result clearly shows that the EDTA solution dissolved anhydrite scale, and the dissolved volume was geometrically calculated to be about 0.4 m^3 which is comparable to the predicted dissolution volume.

After the stimulation, discharge from NF-12 was initiated on the 12th of December 2008. The monitoring of the wellhead pressure and production flowrate indicated their increase after the stimulation as shown in Figure 6. Comparisons between June and December showed that the wellhead pressure increased from 12.4 to 17.3 bar, and the flowrates of steam and water increased from 14 to 22 t/h and from 79 to 118 t/h, respectively. All of these results proved that the EDTA solution is very effective for the removal of anhydrite scale.

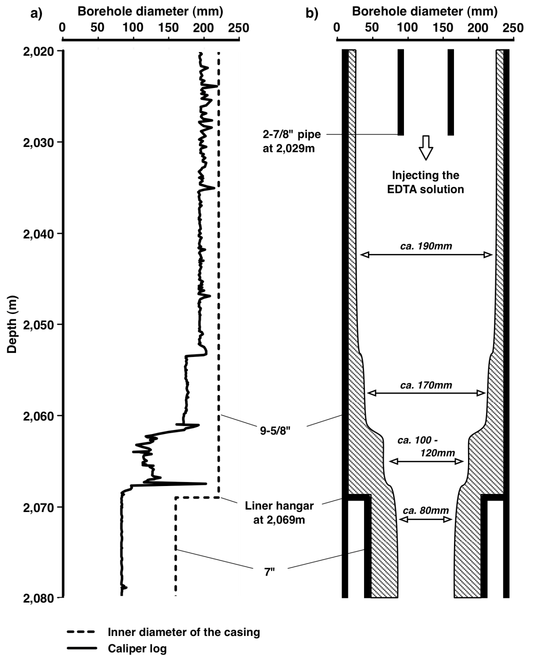

Figure 5: Caliper log and schematic image of residual scale deposit in NF-12 after the chemical well stimulation, showing expansion of the diameter caused by dissolution of the anhydrite scale (see also Figure 1).

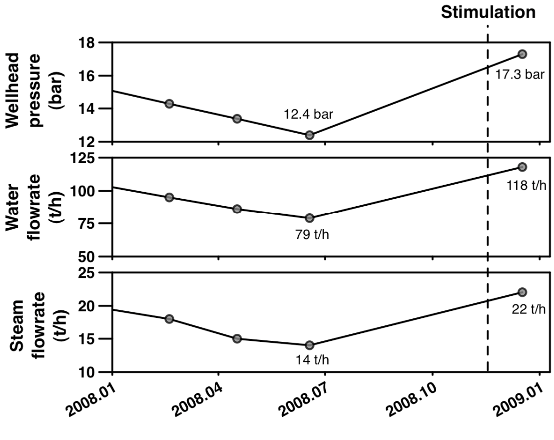

Figure 6: Monitored wellhead pressure and flowrates of NF-12 showing their increases after the stimulation.

5.2 Producer NF-1

Three days after the stimulation, discharge of NF-1 was initiated by airlifting on the 2nd of August 2008. Although NF-1 had previously needed a moderate period of time to complete the initiation, only a short time of airlifting was needed after the stimulation. The monitoring of the wellhead pressure and production flowrate indicated their increase after the stimulation as shown in Figure 7. In comparisons between June and August, the wellhead pressure was found to have increased from 7.9 to 9.1 bar despite increasing the flow control valve from 20 to 22%. The flowrates of steam and brine also increased from 13 to 18 t/h and from 127 to 157 t/h, respectively. In addition, scale fragments were ejected during the production. We thereby interpreted the stimulation using NaOH to be effective for the removal of the Mg-silicate scale.

The scale removal operations described above were the first cases utilizing chelating and alkaline solutions in the Mori geothermal field. In our evaluation, these chemical agents are quite effective for the scale removal.

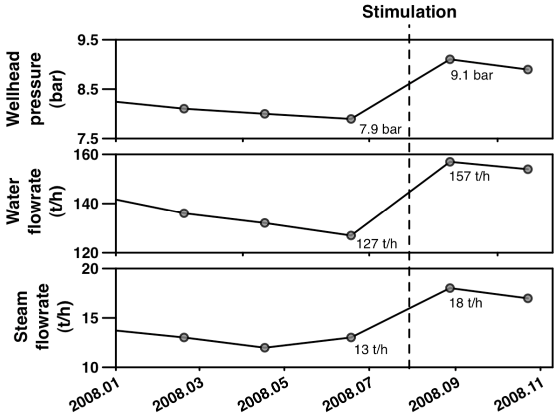

Figure 7: Monitored wellhead pressure and flowrates of NF-1 showing their increases after the stimulation.

6. CONCLUSIONS

A chemical well stimulation approach was applied for scale removal in the producers NF-12 and NF-1 at the Mori geothermal field. A chelating agent, EDTA, was used to dissolve anhydrite scale in NF-12. The dissolution of the scale was confirmed by caliper logging, and both wellhead pressure and production flowrate increased after the chemical stimulation.

An alkaline (NaOH) solution was used in NF-1 to remove Mg-silicate scale, which included an amorphous component thought to be less resistant to the alkali. Scale fragments were ejected from the well during the production, and the wellhead pressure and production flowrate increased after the well stimulation.

These results indicate that the scale removal operation using the chemical agents successfully improved the productivity of the producers.

These stimulation operations were the first such cases in this field, and therefore the conditions of the stimulation (e.g., concentration, volume, and injection rate of the chemical solution) could be optimized through future operations.

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