Scaling in Two-Phase Pipeline (Study Case: Sarulla Geothermal Field)

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Abstract. Sarulla geothermal field is operating 330MW with the combined cycle plant in Indonesia. During the operation of the facilities, there have been many challenges. One of the most prominent obstacles is scaling in the surface facility. Scale deposition is a common problem in geothermal surface facilities. Temperature changes affect thermodynamics reaction which leads to scaling. Precipitation of silica reduces the diameter of the pipe which also reduces the flow rate in the pipeline. Furthermore, the generation will decrease as a result of decreasing the flow rate. In most cases, scale precipitation occurs downstream which has decreased temperature. This field is experiencing scaling in the two-phase environment although it has a higher temperature and in undersaturated condition. This is caused by the mixing of different pH levels of geothermal fluid into the header. In this case, low pH fluid mixed with neutral fluid which also has high silica content. This study investigates and discusses this phenomenon and types of scaling. The result could be used to understand the precipitation process of silica and how to prevent this from happening in the future.

1. Introduction

Sarulla Operations Ltd (SOL) is a consortium that has Geothermal Working Area in North Tapanuli, North Sumatera, Indonesia. This field is operating 3 x 110 MW for a total of 330 MW. During the operation of the facilities, there have been many challenges, some related to scale problems in the production wells and surface piping.

Scale deposition is a common problem in geothermal surface facilities. Normally, it is formed inside the separator or heat exchanger after flashing, where the steam is removed, and silica is concentrated in separated brine [1]. This is related to the deposition of dissolved minerals associated with silica. Silica scaling is affected by many factors, such as temperature, acidity (pH), degree of supersaturation, flow rate, aeration, and other ions in solution [2].

In this case, silica deposition was formed in two-phase pipelines in well pad A. There is a rare phenomenon since most of the scale deposition occurred downstream of surface facilities. This deposition causes a significant decrease in pipe diameter and immensely reduces power generation only within 3 (three) months of operation. Information related chemistry of geothermal fluids will be discussed to understand why this case can occur and how to prevent this from happening in the future.
2. Silica scale in geothermal surface facilities
Silica poses an operational constraint in geothermal field operations due to the formation of scales in surface facilities as the brine cools and ages. From [3], silica exists in many forms and quartz is the predominant form of silica. Scaling in surface facilities is controlled by the temperature of brine, the concentration of dissolved SiO2 in brine, reservoir temperature, brine pH, and salinity [4].

Silica deposition occurred in geothermal wells and surface facilities depend mainly on temperature and when the concentration of silica exceeds the solubility of amorphous silica it becomes over-saturated and forms polymer Silica [5]. Polymerization and deposition of silica scale can be delayed at lower pH [6], while at near-neutral pH the deposition will be rapidly formed (Figure 1) if there is a decrease in brine temperature. The deposition of silica can occur in the form of a crystalline or amorphous phase. Substantively, at least eleven different silica phases with diverse crystalline structures are found in natural and engineered earth systems in various forms such as quartz, opal, or amorphous silica [7].

The presence of cations such as Ca and Mg also can enhance silica polymers and accelerate scaling and residence time of brine in surface facilities [4]. For example, in the Salton Sea and Kyushu geothermal field, iron and aluminum are also incorporated in the amorphous silica deposits by forming bonds of the type Fe-O-Si and Al-O-Si to form the so-called metal-silicates [8]. In other words, it is believed that the deposition rate of silica is enhanced in the presence of metals as cation.

![Figure 1](image.png)

**Figure 1.** Silica polymerization as a function of pH [2].

Metal silicate precipitates at higher temperatures than silica in the form of pure amorphous [9]. This is because amorphous silica solubility is decreased when the concentration of cations, with elevated hydration numbers, increases. Some ions that have been shown to depress the solubility of silica in water include Na, K, Ca, Mg, Sr, and Ba. Some species that have been shown to complex or co-precipitate with silica to form scales include Li, Ca, Mg, Cu, Fe, Mn, Zn, and Al [10].

3. Well pad A configuration and geochemistry
Pad A is located approximately 2 kilometers away from the power plant. This pad consists of three production wells (well-1,2,3) which can generate 55 MW (Table 1).
All these wells merge into the same brine gathering in size 36 which is (* MOV = Motor operated valve), valve to control two-phase flow rate Figure 2.

Fluids from well-1 & 3 have near-neutral pH and well-2 has an acidic condition. Well-2 is online since October 2018 and in assembly with continuous NaOH injection to neutralize the pH to 5.

**Table 1.** Well properties from well pad A in November 2018.

| Well      | WHP (Barg) | Enthalpy (kJ/kg) | Total mass Flow (T/h) | Steam Flow (T/h) | Brine Flow (T/h) |
|-----------|------------|------------------|-----------------------|------------------|------------------|
| Well-1    | 16.8       | 1174             | 489                   | 80.685           | 408.315          |
| Well-2    | 18         | 1139             | 573                   | 84.804           | 488.196          |
| Well-3    | 20.3       | 1267             | 826                   | 175.938          | 650.062          |

* MOV = Motor operated valve, valve to control two-phase flow rate

**Figure 2.** Process diagram in well pad A.

Well-2 is drilled southwest while well-1 & 3 is drilled north. To understand the relationship of each well, fluid properties were drawn using the ternary plot. Based on Figure 3a, it is confirmed that they have different properties of fluid type, which well-1 & 3 are chloride sulfate water and well-2 is volcanic water which related to low pH. By observing Figure 3b, well-2 has immature waters which has the highest magnesium among other wells. This may be indicating water-rock interaction, from acid liquid with rocks or other types of liquid [11].
Figure 3. (a) Cl-SO4-HCO3 ternary plot of well pad A (b) Na-K-Mg ternary plot of well pad A.

4. Preliminary observation

In February 2019, a landslide occurred around the brine gathering pipe location of well pad A which made the pipe broken. This made the steam and brine flow must be temporarily closed until the pipes were repaired. During shutdown, an inspection was done by opening the pipe from two-phase pipeline to the gathering line, and scale had been observed from those surface facilities including two-phase gathering from individual well. Previously, a decrease in flow rate has been observed in all wells in well pad A since well-2 is gathered to the system (Table 2).

Table 2. Flow rate from wells in well pad A during July 2018 – February 2019.

| Flow rate (t/hr) | 3/07/2018 | 14/11/18 | 7/02/2019 | Remarks |
|------------------|-----------|-----------|-----------|---------|
| Well-1           | 642.53    | 481       | 436.7     | Decreased 32% |
| Well-2           | 491.92    | 389       |           | Decreased 20% |
| Well-3           | 1171.08   | 892.6     | 764       | Decreased 35% |

After repaired for nearly two months, wells in well pad A were back online from April 2019. During this operation to July 2019, a significant reduction of flow rate and wellhead pressure was developed again. Table 3 below shows reduction of flow rate and uplift of wellhead pressure during one-month operation.

Table 3. Decrease rate from wells in well pad A during April-July 2019.

| Flow rate (t/hr) | 23/04/19 | 24/07/19 | Remarks  |
|------------------|----------|----------|---------|
| Well-1           | 499      | 293      | Decrease 41% |
| Well-2           | 690      | 105      | Decrease 85% |
| Well-3           | 900      | 448      | Decrease 50% |

| Pressure (barg)  | 23/04/19 | 24/07/19 | Remarks |
|------------------|----------|----------|---------|
| Well-1           | 16.6     | 23       | Increase 38.6% |
| Well-2           | 17.8     | 26.5     | Increase 46.7% |
| Well-3           | 17.4     | 23.5     | Increase 31.4% |

Decline profiles of flow rate in Figure 4 show quite similar with events in February 2019 Table 3. The flow rate in each well has been decreased particularly in well-2. This phenomenon was also affecting generation loss to power plant. We have done preliminary assessments and inspections to observe the origin of this occurrence.
5. Inspection
An inspection for pipelines was carried out to observe the cause of flow rate decreasing corresponding hypothesis that the possibility of scale leading to a reduction of the flow rate. Inspections were conducted twice in April 2019 and August 2019. The examined area includes individual wells, two-phase headers, separators, accumulators, and brine gatherings.

As seen on Figure 5 and Figure 6, from well-1, in the first and second inspection, scales are not found in MOV. Two-phase fluid temperature is always having higher than its saturation temperature and this condition denies scales to deposit. Different from well-1, in the first inspection, there was scale found with minor quantity after MOV in well-2. It is identified as rhodochrosite mineral and it’s in amorphous form (it contains dominantly SiO2 and MnO). In the second inspection, scale that found inside the pipe of well-2 is much thicker than in the first inspection. It reaches 15 cm (5.9”) inside 20” pipe diameter. It is identified as calcite, quartz, and amorphous. The scale found in well-3 MOV also has a small quantity. The scale was found in mineral tetrahedrite form.

**Figure 4.** Flow rate vs wellhead pressure all wells in well pad A.

**Figure 5.** (a) First inspection in February 2019; individual line (after MOV) of well-1; (b) individual line (after MOV) of well-2; (c) individual line (after MOV) of well-3.
Figure 6. The second inspection in August 2019 (a) individual line (after MOV) of well-1 (b) individual line (after MOV) of well-2; (c) individual line (after MOV) of well-3.

When it comes to the two-phase header, the scale becomes thicker (Figure 7). This was started when well-2 which has low pH < 3 was entered the header then mixed with other near-neutral wells. The scale is getting thicker after all three wells were coming into the header. In the first inspection, the thickness of the scales reaches ±15 cm at bottom and top. Scale thickness decreases to 6-8 cm and is more evenly distributed in subsequent surface facilities. In the second inspection, scale deposition already covered half of the inside pipe diameter and decrease to ±8 cm at the downstream before the separator line.

Figure 7. (a) first inspection upstream two-phase header pipeline, (b) first inspection downstream two-phase header pipeline, (c) second inspection upstream two-phase header pipeline and (d) second inspection downstream two-phase header pipeline.
6. Discussion
Continuous observation on this subject is essential since better understanding related to the chemistry of fluid from well pad A is required. The deposition of silica is controlled by temperature and degree of saturation (Silica Saturation index, SSI). Two-phase temperature is crucial for SSI, then it should be maintained above saturation temperature [12]. Once it reaches below saturation temperature, it will lead to silica deposition (Figure 8). In order to further examine the scale, an overview of the process must be carried out.

Table 4. Well properties.

| Well | Sampling date | pH   | SiO₂ (mg/kg) | Cl (mg/kg) | Saturation Temp (°C) | SSI   |
|------|---------------|------|--------------|------------|----------------------|-------|
| well-1 | Nov-18       | 6.04 | 772          | 900        | 174.7                | 0.787 |
| well-2 | Nov-18       | 2.71 | 739          | 1250       | 169.5                | 0.795 |
| well-3 | Nov-18       | 6.53 | 792          | 796        | 176.4                | 0.788 |

Figure 8. Temperature effect on SSI at Well pad A.

6.1. Well-1
Inspection result of well-1 shows there is no scale found in the MOV. This is confirmed by the calculation of SSI that shows the value is less than 1. During the observation, two-phase fluid temperature is always having higher than its saturation temperature.

6.2. Well-2
Individual well properties are shown in Table 4. Only well-2 has an acidic characteristic, but SSI is still < 1. The scale deposition should be not occurred in this condition. However, rhodochrosite and calcite were deposited in line of well-2 and the XRF result shows that the dominant amorphous content is SiO₂ and MnO (Table 5). This silica is the largest one that deposited as a result of low solubility. MnO is the second largest content in scale which can be derived from the content of casing material mixed with...
acid production fluid, or reservoir rock leach. Both of these components can cause a bond of metal silicates; in this case, scaling is in the form of manganese silicates. This is possibly deposited due to injection by caustic soda. This caustic soda is injected due to neutralize the acid properties of well-2. An excessive amount of this injection may lead to the form of rhodochrosite mineral (MnCO3).

6.3. Well-3
Well-3 has the most neutral pH among the other wells in well pad A. During operation, two-phase fluid temperature of well-3 was higher than saturation temperature except for February 2019, which may lead to deposition of scale. And after inspection, scale was found in minor quantity in well-3 two-phase line.

6.4. Two-phase header line
When well-1 and 3 mixes with well-2 fluids, pH increases higher than pH of well-2 fluids. This condition can enhance the precipitation of silica and other minerals. When in individual wells, low pH of well-2 held back the precipitation but after mixing with other near-neutral wells, it can form deposition when temperature operation of well-2 is below saturation temperature. Moreover, from the XRF result, the amorphous phase contains metal such as manganese, iron, magnesium which can form metal silicates. The deposition of silica can enhance by the presence of metal as cations.

| Sample Collected Date | Mineral Identification | Single line well-2 | Single line well-3 | Two-phase header |
|-----------------------|------------------------|--------------------|--------------------|-----------------|
| Apr-19                | Tetrahedrite           | -                  | 36.1               | -               |
| Apr-19                | Rhodochrosite          | 3.9                | 5.6                | -               |
|                      | Amorphous              | 96.1               | 58.3               | 100             |

**Table 5. XRD and XRF result of solid sample in well-2, 3 and two-phase header.**

| Sample Collected Date | Mineral Identification | Single line well-2 | Single line well-3 | Two-phase header |
|-----------------------|------------------------|--------------------|--------------------|-----------------|
| Apr-19                | Al2O3 (%)              | 1.516              | 1.865              | 7.664           |
|                       | Fe2O3 (%)              | 1.126              | 25.983             | 0.61            |
|                       | MgO (%)                | 7.664              | 25.983             | 0.61            |
|                       | MnO (%)                | 0.61               | 51.536             | 26.04           |
|                       | Na2O (%)               | 26.04              | 51.536             |                 |
|                       | SiO2 (%)               | 49.598             | 100                |                 |

| Sample Collected Date | Mineral Identification | Single line well-2 | Single line well-3 | Two-phase header |
|-----------------------|------------------------|--------------------|--------------------|-----------------|
| Aug-19                | quartz                 | 0.5                | 99.3               | 49.78           |
| Aug-19                | calcite                | 0.2                | 94.3               | 45.56           |
| Aug-19                | tennantite             | 5.8                | 100                |                 |
| Aug-19                | amorphous              | 99.3               | 94.3               | 100             |

| Sample Collected Date | Mineral Identification | Single line well-2 | Single line well-3 | Two-phase header |
|-----------------------|------------------------|--------------------|--------------------|-----------------|
| Aug-19                | Al2O3 (%)              | 0.7                | 3.15               | 2.37            |
|                       | Fe2O3 (%)              | 2.64               | 4.14               | 4.04            |
|                       | MgO (%)                | 13.57              | 4.04               | 29.59           |
|                       | MnO (%)                | 17.5               | 1.12               | 1.12            |
|                       | Na2O (%)               | 1.45               | 1.19               | 45.56           |
|                       | SiO2 (%)               | 52.44              | 45.56              | 49.78           |
Simulation using Phreeqc software was used, due to no brine sampling ever done in 2-phase line, when all three wells were online. To generate over-saturated condition on rhodochrosite, carbon was added to the input. If well-2 is not injected with caustic, the fluid mixture of well-1,2 and 3 increase the pH to 5.8 (calculated by GWB software) in a two-phase header. SSI calculated from the line almost reaches over-saturated condition (0.95). However, based on empirical findings, the scale formed is quite thick in the two-phase. Cations such as manganese, iron, and magnesium have quite large components apart from SiO2.

The invariable presence of other cations contributes to form precipitation along with pH increase. In fact, the presence of Mn as scale deposition is not usual in geothermal. In most geothermal brines, manganese does not precipitate directly with silica but in our site, Mn2+ concentration is sufficiently prevalent relative to Mg2+, Ca2+, Fe2+, and Al3+ and form almost pure Mn-silicate scale which is possible according to Manceau and Gallup (2005) [13]. Hence, thermodynamic data is needed to determine the solubility of Mn-silicate.

Figure 9 shows rhodochrosite mineral solubility at some temperatures. An approach of rhodochrosite solubility can be used as a reference in the formation of Mn-silicate since rhodochrosite was found as scale deposit. When well-2 is injected by caustic with pH 5, the mixture of wells reaches pH to 6.4. Temperature range of rhodochrosite formation between pH 6-6.5 is 130-190°C. This shows that at high temperatures, high pH increases the potential for rhodochrosite deposits. pH setting at certain temperatures becomes an important parameter of these deposits. pH monitoring in two-phase header is needed to maintain mixture pH < 6.

![Figure 9. Rhodochrosite solubility.](image)

7. Recommendation
Since the cause of scale deposit has been revealed, there are some recommended solutions to prevent and deal with this condition:

a. Operating temperature must always be higher than the saturation temperature.
   Scale deposition is dependent on temperature then operating temperature must be maintained over-saturation temperature (176 °C).

b. pH modification.
   Well-2 is treated with caustic injection in downhole and surface to reach pH target. The mixture of wells in well pad A will cause the pH increase to 6.4 which also decreases the solubility of rhodochrosite. Lowering pH mixture will decrease the possibility of metal-silicate deposition, in this case, Mn-silicate, by reducing the consumption of caustic surface injection. Therefore, pH checking in downstream two-phase header must be carried out to ensure that the pH is completely mixed and keep it undersaturated and it is maintained < 6.
c. Well-2 should have a separate two-phase header. Well-2 should have a separate two-phase header since it is treated with caustic injection and merge with other similar wells until downstream surface facilities. The impact that can occur is in the downstream facilities since acid wells cannot be combined with neutral wells. If they are combined in the downstream will only change the position of the scale into the downstream area.
d. Shut-in well-2
Since the effect of mixing of an incompatible well is scale deposition which also has an impact on generation loss and additional cost for pipe cleaning, well-2 should be shut-in. Shutting down this well also has an impact on generation reduction.
e. Addition of inhibitor
If well-2 still needs to keep operating, then it is better to use an inhibitor to prevent scale formation. These inhibitors include corrosion inhibitors and scale inhibitors. The selection of inhibitors also needs to be considered and the economic aspect also plays an important role as the inhibitor injections are continuous.
f. Replacement of casing material for well-2
Low pH in well-2 causes corrosion. Besides, leaching from pipe against acid fluid causes an increase of metal content, in this case, manganese. This manganese can accelerate the formation of metal silicate. Therefore, the replacement of casing wellbore to alloy material can reduce the level of metal content formation.

8. Summary and future works
Scale deposition in two-phase header in a well pad is not common in geothermal field. In this study, it has occurred when low pH mixed with near-neutral pH well into the same two-phase header which causes an increase in pH from acid well. Scale deposition was delayed in the acid well since SSI < 1 and low pH held back the precipitation. However, when it comes to two-phase header, pH increases, and precipitate scale can be occurred due to enhancement of metal. Solid sample result shows that metal component as cation surely influences the deposition of metal silicate. The influencing constituent is not only silica but also manganese, magnesium, and iron. However, future studies related to complete thermodynamics data should be done to ensure the formation of metal-silicate.

There are some recommended solutions to prevent and deal with this condition:
a. Operating temperature at two-phase gathering line in well pad A must always be higher than saturation temperature (176 °C).
b. Lowering pH mixture in two-phase line by reducing caustic injection at the surface well-2 line and maintain pH < 6 at downstream two-phase header.
c. Well-2 could flow in separate two-phase line or better shut it in.
d. To minimize scale deposition risk, it is better to add scale inhibitors.
e. Replacement of casing material for well-2.
In the near future, SOL plans to replace casing material for well-2 with high corrosion-resistant material such as Ni-Cr alloy. This new material is expected will prevent massive corrosion from the pipe in acid fluid environment which causes an increase of metal content, in this case, manganese and iron, which accelerate the formation of metal silicate.

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