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# The behavior of silica in geothermal brine from Dieng geothermal power plant, Indonesia

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ABSTRACT

Silica scaling in the Dieng geothermal power plant was investigated experimentally. We conducted two kinds of polymerization experiments to examine the behavior of silica in brine along the canals at production wellpads. Acid-treated and untreated brines were sampled along the canal to understand the effects of acidification on silica polymerization and deposition. Chemical analysis of the Dieng brine indicated high silica and salt concentrations. Silica concentrations of acid-treated brine showed that acidification successfully suppresses the deposition of silica along the canal, preventing it from fulfilling its purpose of depositing as much silica as possible. In contrast, significant silica polymerization occurred along the canal when the brine was not acidified. Batch experiments for silica polymerization at constant temperature indicated that both concentrations of total and monomeric silica decrease quickly in early times followed by gradual decrease with time.



## 1. Introduction

Silica scaling is a common problem in geothermal power generation facilities that inhibits electricity generation (Thorhallsson, 2005). This is because scaling decreases the flow capacity of geothermal fluid in the pipeline network. Injecting geothermal water supersaturated with silica also causes the decrease in injection capacity of wells (Hauksson and Gudmundsson, 1986). This is caused by a reduction in permeability because deposit of silica in fractures in the vicinity of the injection well (Itoi et al., 1989). Therefore, the injection capacity of the well decreases over time and is eventually lost. Once this occurs, the fluid production of a well is controlled by injection fluid capacity, which affects electricity production.

Knowledge of silica scaling is important to overcome this problem both at the surface and sub-surface domains in geothermal power plants. The silica content of a geothermal fluid varies among geothermal fields. The reservoir may contain high concentrations of silica and salt such as in Fushime and Dieng (Takahashi et al., 1988; Geodipa report, 2000]. The prevention and solution of scaling with regard to silica content depends on the salinity of the geothermal fluid.

Under supersaturated conditions, behavior of silica in brine is influenced by pH, temperature, and salinity. Several methods have been introduced to mitigate the formation of silica scale such as acidification of brine to approximately pH 4.5–5.5. Rothbaum et al. (1979) compared normal brine at pH 7.5–9 with acidified brine at pH 4. The acidified brine formed scales with significantly lower rate of up to one to 100 times than the unacidified one. They suggested that acidification of brine may be a practical method to minimize scale formation. Gallup (2002) used an organic inhibitor instead of acid to control silica deposition. The acidification method is effective and the most inexpensive compared with other scale inhibition methods but can lead to corrosion (Carlos and Patricia, 2012).

It is difficult to avoid supersaturated condition in brine once the silica concentration is high. As a result, silica deposition tends to occur in specific places such as the canal before flowing to the reinjection well. Yokoyama et al. (1987) studied the behavior of silica in geothermal water in the aging tank at Hachobaru. Their results showed that the concentration of monomeric silica decreased as it flowed downstream in the aging tank. The monomeric silica concentration along the aging tank showed good correlation with the amount of deposit on the wall of aging tank. This also indicates

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that monomeric silica is a control factor of deposition. Weres and Tsao (1981) studied the precipitation of amorphous silica from synthetic geothermal brines that resembled the flashed brine at Cerro Prieto, Mexico. They found that a part of the dissolved silica quickly polymerizes to form suspended colloidal silica.

Separated brine from the produced fluids at wells in Dieng has high concentrations of both silica and salt as shown in Table 2. To avoid silica scale formation at reinjection well facilities, a canal and pond system has been employed. Investigation of silica in the brine while flowing in the canal is necessary to understand how silica affects scale formation in there injection facilities. This paper aims to examine the ability of canals and ponds to cope with scale formation.

## 2. Counter measures for silica problems in Dieng

Geothermal fluid in the Dieng reservoir is probably in liquid single-phase condition as compressed water. It then starts flashing in wellbore, and both the temperature and the pressure decrease as the steam-water two-phase mixture flows upward in the wellbore. Discharged fluid from the well is separated at the separator into steam and brine. The steam is transported to the turbine for power generation while the brine flows into flasher. Since the flasher pressure is controlled by ambient pressure, the fluid temperature drops to that in saturated liquid condition. The brine then is discharged to the canal and flows for a specific distance, and flowed into ponds from where the brine is pumped to reinjection wells (Fig. 1).

### 2.1. Canal system

In Dieng, the canal and pond are a relatively new system to avoid silica deposition in reinjection wells. Before employing this system, separated water was directly sent to reinjection wells as a high temperature reinjection system. However this system failed because the injection pumps could not be maintained. The silica concentration of the brine is significantly high and deposition damaged the pump. A new system lets brine flow through a canal to a pond. In this system the brine temperature drops through the canal and significant amounts of silica are deposited. The brine stays in the pond for a while before it is pumped to reinjection wells. Although the canal and pond system aims to enhance silica deposition, silica still remains in the brine and will deposit in the reinjection pipeline as shown in Fig. 2.

### 2.2. pH control

The acid dosing system using $H_2SO_4$ has been installed in Dieng at the outlet of the separator to control pH of the brine. Since the original brine pH is neutral, acid is added to decrease the pH then suppress the silica polymerization. Without this acidification, silica scale may occur in the flasher as well as reinjection pipeline.

**Fig. 1.** Silica scaling in injection line.

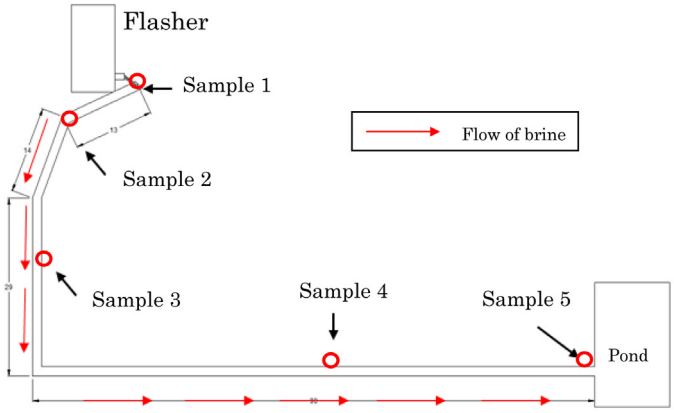


**Fig. 2.** Schematic of canal and sampling locations along the canal at wellpad 1.

## 3. Field experiments

Experiments were conducted at wellpads 1, 3, and 4 where canal system were installed to enhance silica deposition prior to discharge into a pond and pumping of the cooled brine to an injection well. Consequently, silica concentration in the brine would be lowered by the time when the brine being discharged into the pond, and then the brine pumped to reinjection wells. At the same time, acid has been added into the brine at the outlet of the separator to avoid silica deposition. Prior to these experiments the effect of acidification on silica deposition had not yet been quantitatively evaluated. Two kinds of experiments were carried out in this study: silica concentration analysis in brine along canals and a polymerization experiment of silica in brine at constant temperature as batch experiment. Brines of acid-treated and untreated fluid were sampled along canals at two wellpads. Production wells were under different for operational conditions when experiments conducted either under full production or breeding. The experimental design is summarized in Table 1.

### 3.1. Concentration of silica in brine along the canals

To observe the concentration of silica along the canal, brine samples were taken at specific locations at wellpads 1, 3 and 4. Figs. 2–4 show schematics of the canal system designs and sampling locations in respective canals.

#### 3.1.1. Wellpad 1

In wellpad 1, we collected the samples at five locations as shown in Fig. 2. The first sample is taken at the outlet of the flasher. Then, 13 m after, sample 2 was collected. Samples 3 and 4 were taken in the middle of the canal and the last sample was at the end of the canal just before flowing into the pond. In wellpad 1 both acid treated and untreated fluids were sampled.

**Table 1**
Experiments carried out at different wellpads.

| Experiment | Brine conditions | Wellpad |
|---|---|---|
| Silica concentration along the canal | Acid treated | 1 |
| | Untreated | 1, 3, 4 |
| Polymerization experiment of silica behavior in brine at constant temperature | Acid treated | – |
| | Untreated | 1,4 |

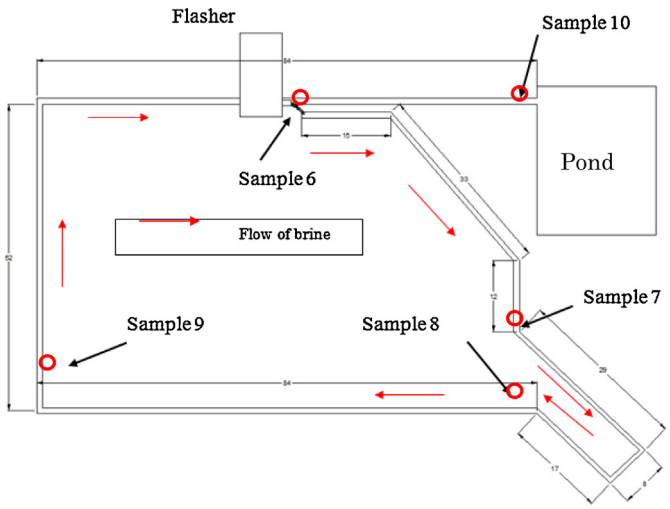


**Fig. 3.** Schematic of canal and sampling locations along the canal at wellpad 3.

*3.1.2. Wellpad 3*

In wellpad 3, five samples were collected named Samples 6–10 as shown in Fig. 3. The location where the samples are taken is quite similar with wellpad 1. For first sample, is taken from the flasher outlet. Second, third and fourth samples are taken in the middle of canal while the last sample is taken before the ponds.

*3.1.3. Wellpad 4*

In wellpad 4, five samples are taken from the canal as shown in Fig. 4. The location distances are in 0 m, 100 m, 200 m, 300 m and 400 m. The canal in wellpad 4 has the longest distance among wellpads in Dieng.

*3.2. Polymerization experiment of silica behavior in brine*

Brine flowing in the canal changes in concentrations of monomeric silica and polymerized silica. To understand the polymerization behavior of silica in the brine under constant temperature, experimental equipment was developed using plastic container that immersed into the canal as shown in Fig. 5.

The experimental apparatus consists of a plastic container, plug for the container, rod, basket, and basement. Around 0.75 L of Brine discharged from the flasher was taken with a bucket, then immediately poured into the container of 1 L container. The container was covered and immersed in the canal to keep it constant temperature. The plug allowed access for sampling. A basket and wire brace were used to hold the container. The rod and basement kept the basket at a suitable position. The brine in the container was

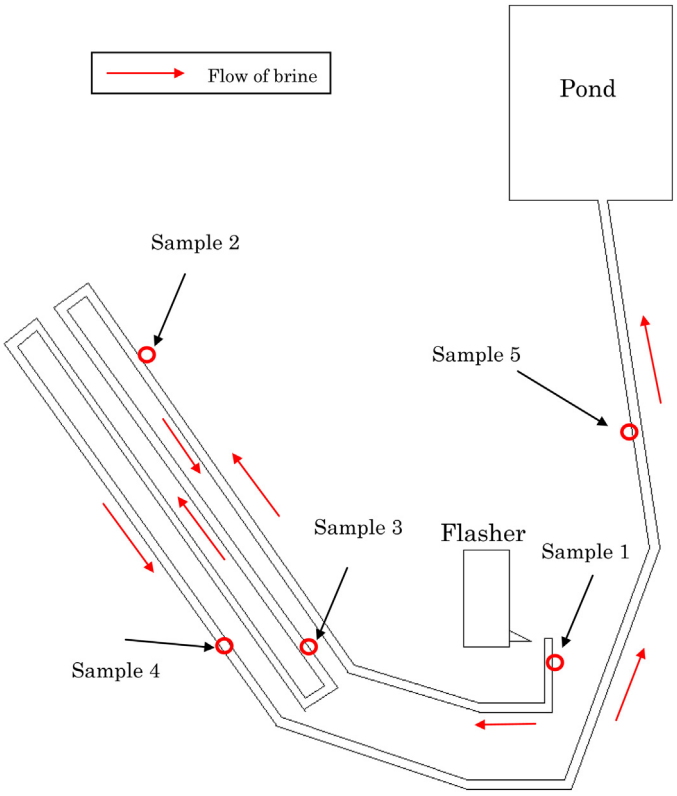


**Fig. 4.** Schematic of canal and sampling locations along the canal at wellpad 4.

sampled at time intervals of 5 min in early times and up to 30 min in latter times. Brine samples collected with a micropipette were processed the same as the samples collected along the canal.

## 4. Methods

*4.1. Sampling method and measurement in situ*

*4.1.1. Brine sampling method*

We collected brine samples at several points along the canal. 5 ml of brine was taken with micro pipette and put into 100 ml flask which was already filled with 40–45 ml of distilled and added with 1 ml of 1 N $H_2SO_4$. Then, the flask is filled with distilled water to 100 ml. The objective of adding $H_2SO_4$ is to maintain brine mixture in acidic condition below pH 2 in order to suppress further polymerization of silica in brine samples.

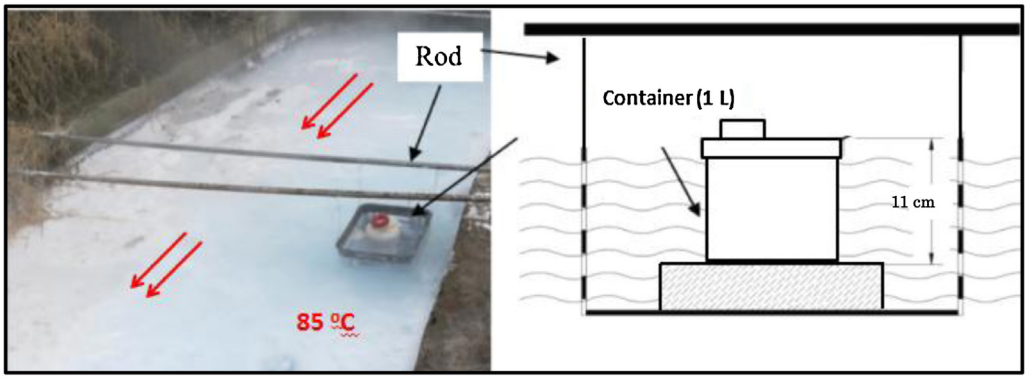


**Fig. 5.** Setup for a batch experiment in the canal and schematic of equipment.

**Table 2**
Chemical composition of Dieng geothermal fluid.

| Element (ppm) | Well 1 | Well 3 | Fushime[a] | Ohtake[a] | Hatchobaru[a] |
|---|---|---|---|---|---|
| $SiO_2$ | 1400 | 1145 | 555 | 555 | 849 |
| Cl | 21,400 | 28,400 | 16,700 | 1770 | 3070 |
| $SO_4$ | – | – | 48.1 | 190 | 154 |
| Li | 40 | 60 | 8.46 | 5.51 | 12.3 |
| Na | 8340 | 11,460 | 9000 | 1120 | 1850 |
| K | 2520 | 3340 | 1060 | 129 | 294 |
| Mg | – | – | 9.47 | 0.12 | 0.80 |
| Ca | 440 | 860 | 1040 | 51 | 32.5 |

[a] Takahashi et al. (1988).

#### 4.1.2. pH and temperature measurement

Temperature and pH were also measured at each sampling location with thermometer and pH meter.

### 4.2. Chemical analysis method

Silica concentration for both total and monomer silica were analyzed with the molybdenum yellow method (Nollet, 1948). For total silica concentration, 5 ml of sample was added with 0.5 ml of 1 N NaOH, and then heated in a platinum plate at 80 °C for 10 min to breakdown polymerized silica into monomer silica. Then, concentration of monomer silica was analyzed with U-1800 Ratio Spectrophotometer. Brine samples were analyzed for cations ($Li^+$, $NH_4^+$, $Na^+$, $K^+$, $Mg^{2+}$, and $Ca^{2+}$) and anions ($Cl^-$, $SO_4^{2-}$) with ion chromatography (Dionex ICS-90).

## 5. Results and discussion

### 5.1. Chemical composition

Table 2 shows the results of chemical analysis of anions and cations in brine from wellpads 1 and 4 at the Dieng geothermal power plant. The salt concentration of Dieng samples is significantly high compared with other geothermal fluids from Fushime, Ohtake, and Hachobaru. The concentration of $Cl^-$ indicates 21,400 and 28,400 ppm for brines at wellpads 1 and 4, respectively. In contrast, $Cl^-$ at Ohtake and Hachobaru were relatively low at 1770 and 3070 ppm, respectively. However, the chloride concentration at Fushime is similar to that of Dieng geothermal fluid. $Na^+$ concentration of samples from Dieng and Fushime is considerably higher than that measured in fluid from Ohtake and Hachobaru.

### 5.2. Temperature and pH measurements

Table 3 presents the temperature and pH measured along the canals for wellpads 1 and 3 at specific distances. The distances in these measurements differ from those in Experiment 1. The pH differs between wellpads 1 and 3. Wellpad 1 brine samples are more acidic than those from wellpad 3, because samples from wellpad 3 were untreated with acid. The first sample at 0 m means that the brine was collected at the outlet of the flasher.

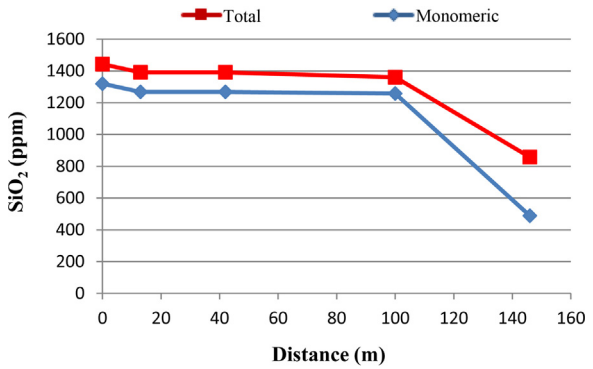


**Fig. 6.** Total and monomeric silica concentrations for samples collected along the brine canal of wellpad 1 with acid injection.

### 5.3. Silica concentration along the canal

In this experiment, there are two brine conditions: acid treated and untreated. Wellpad 1 was operated under both acid-treated and untreated conditions. Therefore, the effect of acid treatment on the behavior of silica in this wellpad can be evaluated. Other wellpads such as 3 and 4 were operated under untreated conditions.

#### 5.3.1. Wellpad 1 under acid-treated condition

The total concentrations of silica in Sample 1–4 from wellpad 1 remain almost constant as shown in Fig. 6. Monomeric silica concentration also shows similar behavior. However, both concentrations in Sample 5 decrease. pH value of Sample 5 indicates 4.5, which is higher than those in Samples 1–4 being about pH 3.2. We are unsure why the pH of Sample 5 is higher than that of other samples collected in the same canal. Therefore, we only discuss the trend of Samples 1–4. Marked polymerization of silica in wellpad 1 did not occur, because there is small difference between the total and monomeric silica concentrations among these samples. Therefore, acid injection suppresses silica polymerization in the brine while flowing in the canal. Furthermore, the total silica concentration in Sample 1–4 remains constant, which implies silica deposition, does not occur in the canal. Thus, acid treatment also successfully suppresses the deposition of silica along the canal.

#### 5.3.2. Wellpad 1 without acid treatment

Fig. 8 shows the silica concentrations with distance along the canal at wellpad 1 when the brine was not acid treated. The total silica concentration at the outlet flasher is 971 ppm while the monomeric silica concentration is 498 ppm.

The difference of these concentrations implies that a part of the silica in the brine has been already polymerized before the flasher outlet. The concentrations of both total and monomeric silica decrease markedly along the canal. At the end of the canal at a distance of 145 m, the concentrations of total and monomeric silica are 745 and 265 ppm, respectively. This indicates that silica was deposited along the canal because the total concentration of silica decreases as the distance along the canal increases.

**Table 3**
Temperature and pH measured along the canal at wellpads 1 and 3.

| Wellpad 1 | | | | Wellpad 3 | | | |
|---|---|---|---|---|---|---|---|
| ID | Distance (m) | pH (–) | $T$ (°C) | ID | Distance (m) | pH (–) | $T$ (°C) |
| Sample 1 | 0 | 3.20 | 89.0 | Sample 6 | 0 | 6.26 | 85.0 |
| Sample 2 | 13 | 3.21 | 84.8 | Sample 7 | 60 | 6.25 | 62.4 |
| Sample 3 | 42 | 3.20 | 82.2 | Sample 8 | 115 | 6.29 | 51.4 |
| Sample 4 | 100 | 3.25 | 76.0 | Sample 9 | 200 | 6.27 | 50.2 |
| Sample 5 | 146 | 4.50 | 73.8 | Sample 10 | 334 | 6.32 | 47.8 |

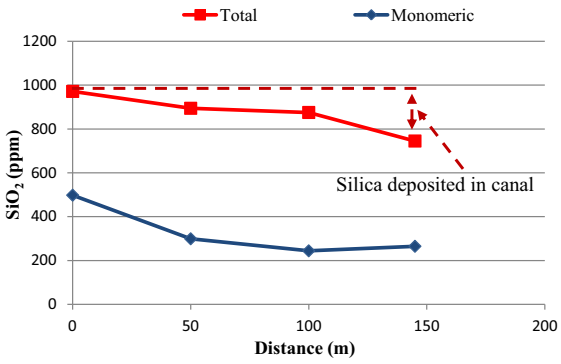


**Fig. 7.** Total silica and monomeric silica concentrations along the canal at wellpad 1.

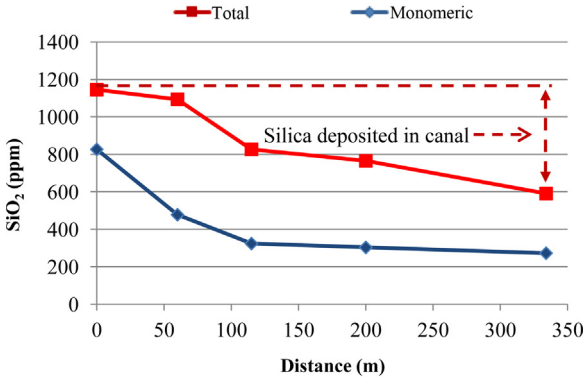


**Fig. 8.** Total and monomeric silica concentrations for samples collected along the brine canal of wellpad 3 without acid injection.

### 5.3.3. *Wellpad 3 without acid treatment*

Fig. 8 shows the total and monomer silica concentrations in brine samples collected at wellpad 3. The total silica concentration of Sample 6 after discharge from the flasher is 1145 ppm whereas the monomeric silica concentration is 827 ppm, indicating that of polymerized silica is 318 ppm. In contrast to the silica concentrations of brine at wellpad 1 shown in Fig. 7, both the total and monomeric silica concentration decrease as the brine flows downstream.

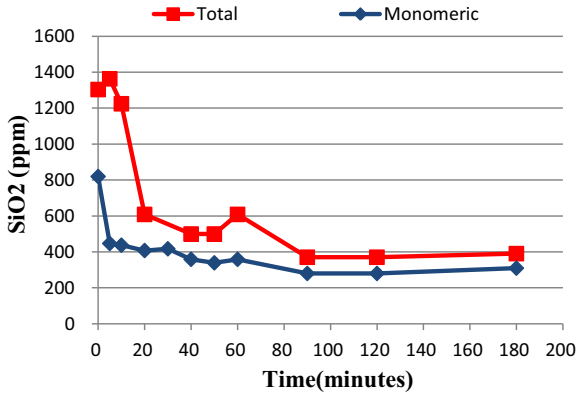


**Fig. 10.** Changes of total and monomeric silica concentrations with time for batch experiment in wellpad 1.

The total silica concentration of Sample 10 is 600 ppm. This sample was collected at the end of the canal just before the brine was discharged into the pond. The concentration difference between Sample 1 and Sample 6 is about 600 ppm, which represents the silica deposited along the canal. Under these conditions, the canal system can be successfully used to enhance silica deposition from the brine.

### 5.3.4. *Wellpad 4 without acid treatment*

The total length of the canal of wellpad 4 is longer than that of wellpad 1. Fig. 9 depicts the concentration of samples taken at specific distances. Both total and monomeric silica concentrations decrease along the canal, so the deposition of silica occurred. The total silica at the outlet of the flasher is 816 ppm while it is 755 ppm at a distance of 400 m (Sample 5).

### 5.4. *Polymerization experiment*

In this batch experiment, only untreated brine was used. The total and monomeric concentrations of silica in the brine at wellpads 1 and 4 were analyzed. The experiments were conducted under constant temperature, about 80 °C, by immersing the plastic container in the canal. The constant temperature value is fixed to understand the characteristic of silica (Fig. 10).

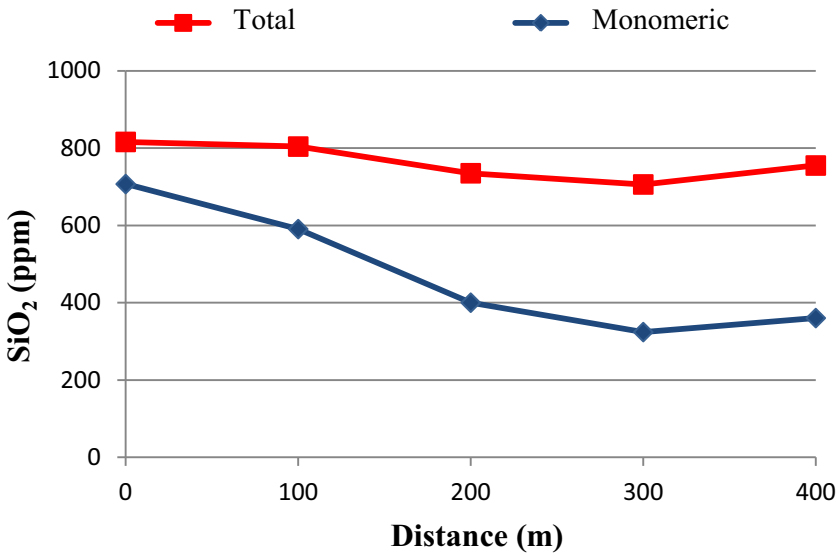


**Fig. 9.** Change of total silica and monomeric silica concentrations with distance in wellpad 4.

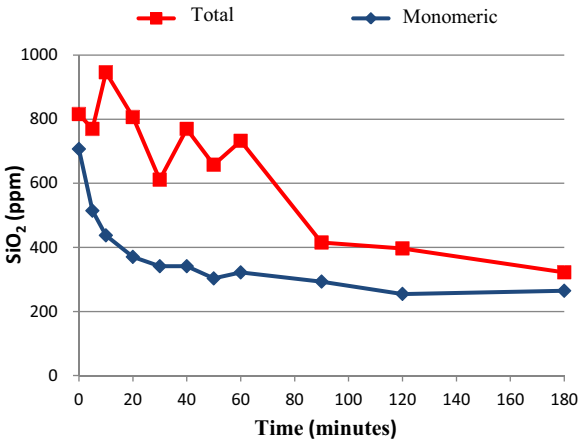


**Fig. 11.** Changes of total and monomeric silica concentrations with time for batch experiment in wellpad 4.

*5.4.1. Wellpad 1*

Fig. 11 shows concentration changes both in total and monomeric silica concentrations with time for the brines from wellpad 1. Duration of the experiment was 180 min. The total silica concentration quickly decreases from 0 to 25 min, then its decrease rate become rather gradual. Visual observation of the brine in the plastic container when sampling brine indicates that gel like material is formed at the bottom of container. The concentration of monomeric silica also decreases quickly in early times followed by gradual decrease. The difference between the total and monomeric silica concentrations represents the polymerization of silica. Furthermore, the decrease in the total silica concentration implies a deposition of silica or a formation of silica gel. From these results, the brine in this wellpad can successfully decrease in its silica concentration in the form of deposited silica or silica gel in 25 min after discharged from the flasher. Thus, the canal system works effectively in terms of lowering silica concentration in the brine. Under untreated brine conditions, a canal system with a residence time of 25 min can be constructed to achieve a large decrease of silica concentration.

*5.4.2. Wellpad 4*

Fig. 11 shows the changes in total and monomeric silica concentrations in the canal of wellpad 4 over time. A similar trend was observed to that in Fig. 11. However, the decrease rate in total silica concentration was slow compared to that for wellpad 1. The reason for this is related to the total concentration of silica and salt concentration in the brine since salt avoids polymerization chemically. However, we can conclude that the canal system successfully increases the deposition rate of silica.

## 6. Conclusions

In the Dieng geothermal field, high concentrations of both silica and salt in brine causes a serious scaling problems in reinjection pipe line as well as reinjection wells. In order to mitigate this problem, a canal and pond system has been employed to enhance silica deposition along the canal, thus silica concentration in brine is decreased before reinjection. At the same time, acid treatment of the brine was also introduced to suppress either silica polymerization or silica deposition. This study aims to understand silica behavior in the brine along the canal and polymerization phenomena in the brine with batch experiment under constant temperature.

Brines collected from the canals have two conditions: acid-treated and untreated. Silica concentrations in brines along the canal under these conditions indicate that acidification of the brine down to pH 3.2 successfully suppresses the deposition of silica along the canal because the total and monomeric concentrations of silica in brine samples remain constant. This result, however, disregards the purpose of the canal system which aims to enhance silica deposition along the canal as much as possible. For untreated brine, significant polymerization occurred in brines along the canals in wellpads 1, 3, and 4.

Batch experiment under constant temperature revealed that total and monomeric silica concentrations decrease quickly in early times followed by a gradual decrease with time, indicating the canal system works successfully with its designed length.

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