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Study on Silica Scaling at Open Canal System, Dieng Geothermal Power Plant, Indonesia

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ABSTRACT

At open canal system in the Dieng geothermal power plant, Central Java, Indonesia, the polymerization of silicic acid in geothermal water and the precipitation of silica scales were investigated. The polymerization was examined by spectrophotometrically measured total silicic acid and monosilicic acid concentrations. Silica scale samples were obtained by immersing copper plates in geothermal water. The obtained silica scale samples on copper plates were characterized by XRD.

Sulfuric acid is added into geothermal water to lower pH and to retard the deposition of silica scales at Dieng geothermal power plant. Under neutral pH condition (before the acidification), monosilicic (SiO_2-M) and total silicic acid (SiO_2-T) concentrations decreased simultaneously, suggesting that the rapid polymerization of silicic acid and the formation of polysilicic acid (SiO_2-P) with particle size larger than 0.45 μm proceeded at the same time. Under acidic pH condition (after the acidification), SiO_2-T concentration was constant (1300 ppm SiO_2), however SiO_2-M concentration decreased, suggesting that although polymerization of silicic acid occurred, the growth of the particles was retarded.

Iron is well known to affect the silica scale formation. In the open canal system, with the decreasing of total silicic acid concentration under neutral condition, iron concentration in geothermal water was also decreased, suggesting that iron may be incorporated into polysilicic acid during the polymerization. In addition, iron may accelerate the reaction among monosilicic acids during the early polymerization stage. On the other hand, decreasing of iron concentration in geothermal water was retarded under acidic condition in accordance with total silicic acid concentration. It is possible that acidification by sulfuric acid may also limit the interaction between iron and monosilicic acid.

Silica scale formed under acidic condition contained higher contents of iron than those formed under neutral condition. According to the XRD results, silica scale formed on the surface of copper plate mainly consists of amorphous silica. Some iron minerals were detected in the silica scale formed under acidic condition (e.g. magnetite). In addition, silicic acid adsorption experiment on silica gel suggests that silicic acid can be adsorbed on silica scale (represented by silica gel) even under acidified condition and without incorporation of iron.

1. INTRODUCTION

Dieng geothermal power plant, located in Banjarnegara, Central Java, Indonesia, is operated by PT Geo Dipa Energi. Since the beginning of its operation in 2002, silica scale problem has become a major problem on the development of geothermal energy there. Silica scale is formed in almost every part of surface facilities, including two-phase fluid transportation pipe, separator, brine pipe, and reinjection pipeline. Wellpad with the highest capacity has the most severe silica scale problem, hence it is very important to tackle the problem to keep energy production. The wellpad consists of one production well with two separators due to high productivity of this production well (see Figure 1). Brine water from separators flows through two different brine pipes to two air-flasher tanks. Water discharged from air-flasher tanks finally mixed at open canal and pond system before enters reinjection pipeline, and pumped to reinjection well. Two approaches are currently applied by the company to tackle silica scale problem in this wellpad: acidification by sulfuric acid and decreasing temperature by open canal and pond system. Acidification is applied to prevent the formation of silica scale (silica polymerization) in brine pipe, connecting separator and air-flasher tank. Meanwhile open canal and pond system are built to decrease temperature of geothermal water and let silica precipitate before geothermal water enters reinjection pipeline. However, the effectivity of open canal system is decreased due to acidification of geothermal water.

Dieng geothermal power plant consists of several production wells characterized by steam-rich, brine-rich, and two-phase fluid. This study emphasize on the formation of silica scale in the two-phase well which has the highest electric capacity (almost half of the total capacity of Dieng geothermal power plant). Geothermal water from this well is characterized by high salinity and high silica content as shown in Table 1. Chloride concentration is up to 21,200 ppm, while concentration of sodium, potassium and calcium are 10,249 ppm, 2,817 ppm, and 708.8 ppm, respectively. Likewise most geothermal reservoir water, magnesium concentration of Dieng geothermal water is also very low (0.5 ppm), while sulfate and bicarbonate is also low (74.4 ppm and 25.02 ppm, respectively). At two-phase pipe, total silicic acid concentration of Dieng geothermal water is 1,064 ppm, while Fe and Al concentrations are 1.35 and 0.01 ppm, respectively. Concentration of silica and iron significantly increase to 1,200 ppm and 2 ppm, respectively after the outlet of air-flasher tank due to phase separation of two phase fluid and flashing.

Table 1: Geochemical characteristic of Dieng geothermal water

Cl	SO_4	HCO_3	Na	K	Ca	Mg	SiO_2	Al	Fe
ppm									
21,200	74.4	25.02	10,249	2,817	708.8	0.5	1,064.5	0.01	1.35

Precipitation of silica in geothermal water is closely related with the polymerization of silicic acid as has been studied for the past decades by several researchers (e.g. Kitahara, 1960, Rothbaum et al., 1979, Weres et al., 1981, and Tarutani 1989). Furthermore, many studies show the importance of salts (e.g. potassium, sodium, calcium and chloride) and metals (e.g. aluminum, magnesium, and iron) in the formation of silica scale (Gallup and Reiff, 1991; Manceau et al., 1995; and Yokoyama et al., 1993). This study focuses on the role of iron in the deposition of silicic acid in geothermal water at open canal system of Dieng geothermal power plant, and the effect of acidification by sulfuric acid to prevent silica precipitation.

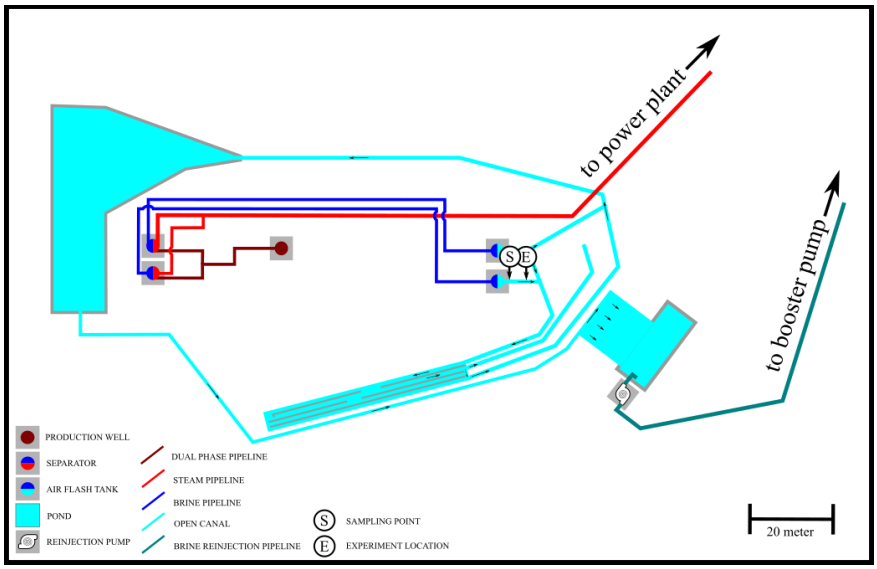

Figure 1: Sketch map of wellpad of interest in Dieng geothermal power plant.

2. METHODS

2.1 Experimental procedure

Batch experiment was conducted on-site at open canal system of Dieng geothermal power station. The experiment was conducted under neutral (6.5) pH condition (before injection of sulfuric acid) and acidified (5.3) pH condition. One liter of geothermal water was taken from the outlet of air-flasher tank (the beginning of open canal system) and was put into polypropylene bottle as reaction vessel. The bottle was put on the flowing hot geothermal water to maintain its high temperature (80 – 90 °C) (see Figure 2). Each experiment was conducted for two hours, however, some experiments are extended until 4 hours. An aliquot of geothermal water (50 mL) was taken from the reaction vessel at each designated reaction time, filtered by 0.45 µm membrane filter, and acidified with 0.1 M nitric acid to prevent further polymerization. The collected water samples were then analyzed spectrophometrically to determine monosilicic acid concentration, while some other samples were brought to Kyushu University for ICP-OES analysis.

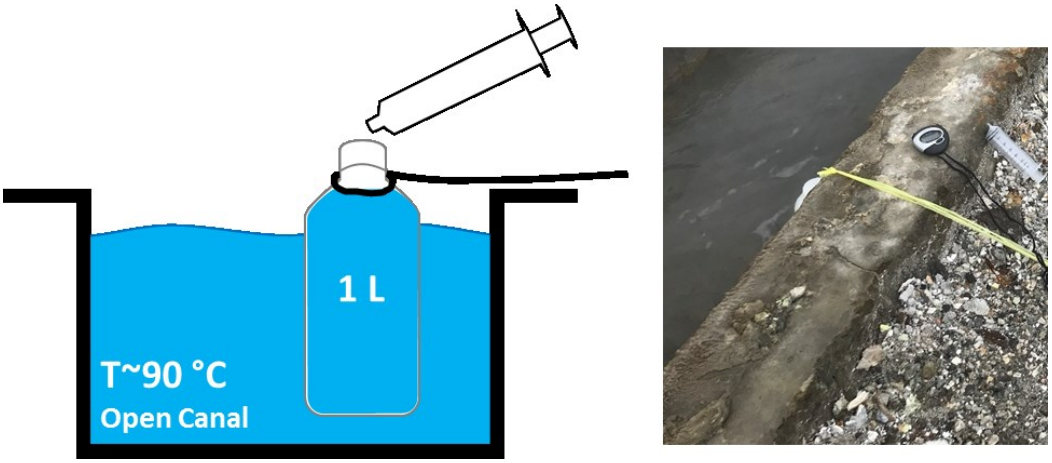

Figure 2: Schematic diagram (left) and photograph (right) of batch experiment at open canal system.

In addition, adsorption experiment of silicic acid on silica gel was also carried out to investigate the interaction between silica scales previously deposited at open canal and silicic acid in geothermal water. The experiments were conducted on a similar procedure as polymerization experiment. To understand the interaction mechanism, two types of silica gel D-50-1000AW and Mallinckrodt silica

gel were investigated. Specific surface area of D-50-1000AW and Mallinckrodt is 28 m^2/g and 350 m^2/g, respectively. Change of concentration of monosilicic acid, total silicic acid and total iron were then observed to understand the effect of each silica gel.

In order to characterize the deposited silica scale on open canal, plate test experiment was demonstrated. Several copper plates were immersed in open canal to let silica precipitate on its surface (Figure 3). The experiment was carried out under two different pH conditions: neutral pH condition for 1 day, neutral pH for 3 days followed by acidified condition for 4 days, and neutral pH for 3 days followed by acidified pH for 14 days. The deposited silica on copper plate surface were collected and analyzed by means of X-ray diffraction for mineralogical characteristics as well as ICP-OES and AAS for metal content determination after digestion of the precipitates.

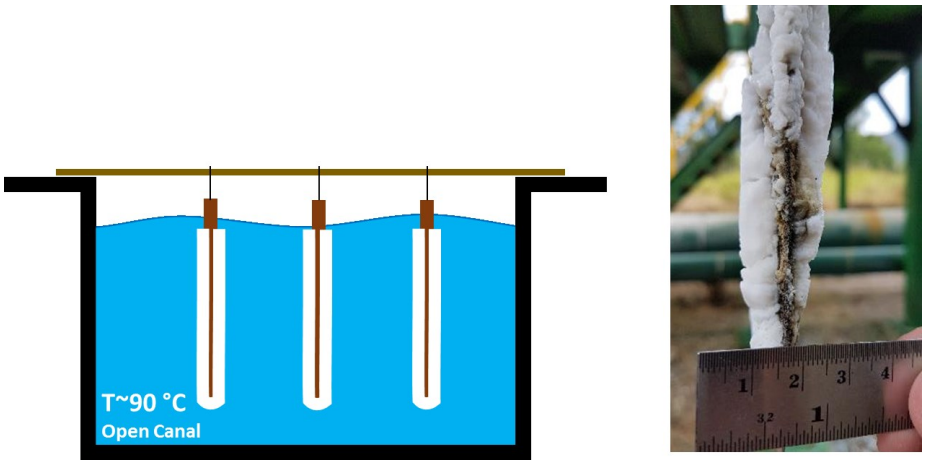

Figure 3: Schematic diagram (left) and precipitation result (right) of siliceous deposit on copper plate test.

2.2 Analytical methods

2.2.1 Water samples

In order to determine the chemical composition of water samples, spectrophotometry analysis and ICP-OES analysis were conducted. Spectrophotometry analysis was conducted on-site using HACH DR-1900 instrument to determine monosilicic acid. Geothermal water samples were diluted and acidified with 0.1 M nitric acid, and mixed with 5 wt% molybdate. The molybdosilicic acid complex showed yellowish color. The solution was then spectrophotometrically analyzed at 400 nm wavelength. Concentration was calculated from absorbance value obtained from the analysis based on standard solutions. Inductively couple plasma – optical emission spectroscopy (ICP-OES) analysis was carried out using Perkin-Elmer Optima 5300DV instrument to obtain total silicic acid (SiO_2 (T)) concentration and iron (Fe) concentration in the samples. This analysis was conducted in Economic Geology Laboratory, Kyushu University, Japan.

2.2.2 Deposit samples on copper plate

The collected silica deposits on copper plate were analyzed by means of X-ray diffraction using Rigaku UltimaIV. The collected silica deposits were rinsed using ultrapure water and air-dried for 48 hours prior to the analysis. As for chemical characteristic of the deposit, ICP-OES and AAS (atomic absorption spectroscopy) were employed to determine metals (Fe, Al and Mg) in the deposited material. The solid samples were grinded into powder and dissolved into solution by concentrated HF (hydrofluoric acid) and nitric acid.

3. RESULTS

3.1 Change of silicic acid and iron concentration

The variation of concentrations of monosilicic acid, total silicic acid and Fe obtained through spectrophotometry and ICP-OES analysis were shown in Figure 4. Under neutral pH condition monosilicic acid (SiO_2 (M)) concentration was rapidly decreased from 834.3 ppm to 329.7 ppm within 60 minute polymerization experiment (see Figure 4a). Likewise, total silicic acid (SiO_2 (T)) concentration also decreased rapidly from 1,161.6 ppm to 343.6 ppm. This result shows that under neutral pH condition silicic acid is rapidly polymerized and formed polysilicic acid which then grew to larger particle than 450 nm, hence silicic acid was removed from geothermal water. Similarly, total iron (Fe) concentration also decreased rapidly from 2.06 ppm to less than 0.05 ppm (detection limit of ICP-OES). These results suggest that Fe is almost completely removed from geothermal water along with the deposition of silicic acid.

On the other hand, both SiO_2 (T) and Fe concentrations remained high level during polymerization experiment under acidified pH of 5.3 (Figure 4b). SiO_2 (T) concentration was initially 1,276.1 ppm, and almost maintained within 60 minutes. Fe was also kept at constant during the experiment. It is clear that SiO_2 (T) and Fe precipitated in much slower rate under acidified pH condition than that under neutral pH. However, concentration of SiO_2 (M) gradually decreased from 1,141.1 ppm to 406.7 ppm. This suggests that polymerization still occurred under pH 5.3, even though the growth of polysilicic acid was clearly suppressed.

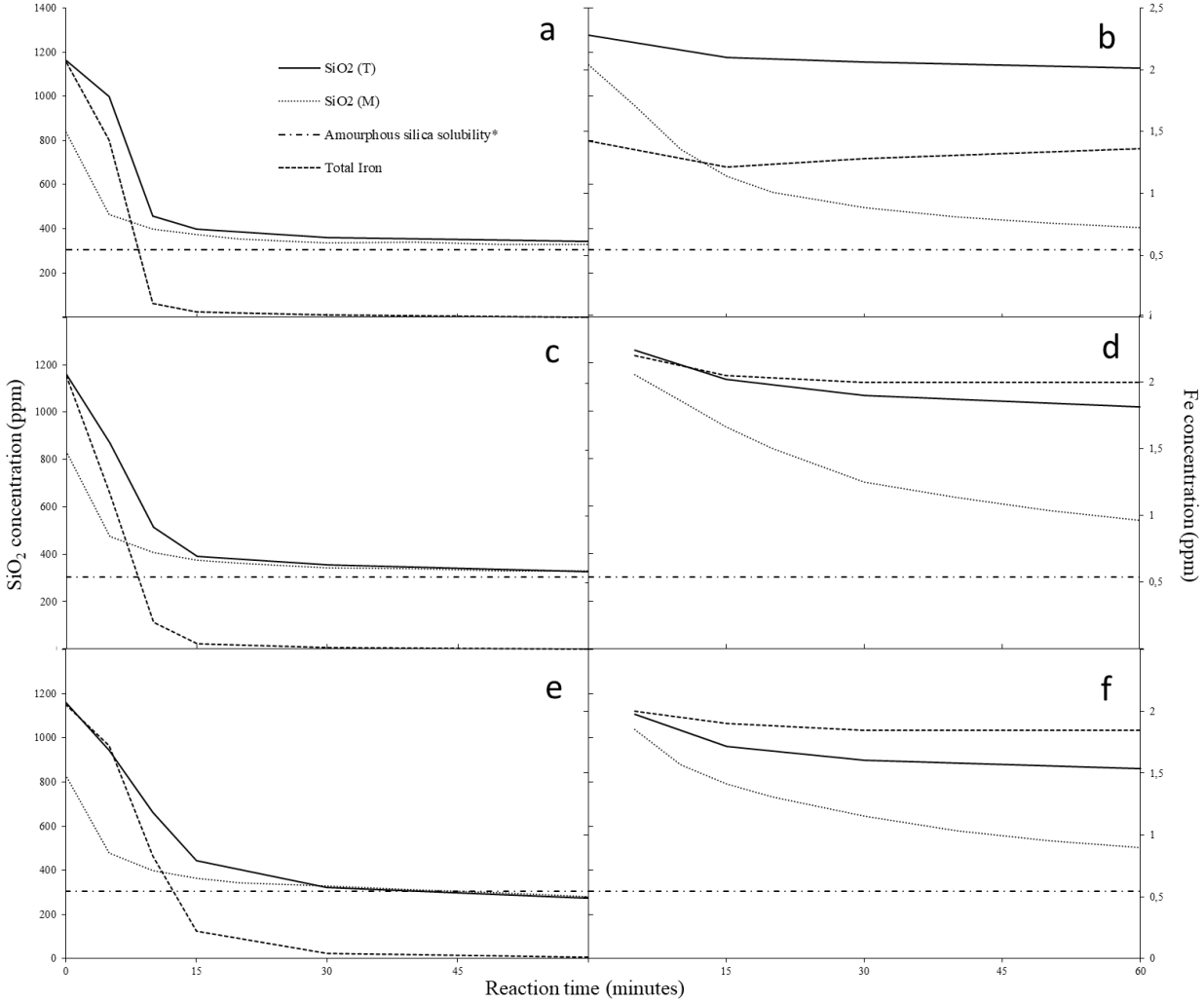

Figure 4: Change of silicic acid and Fe concentration in geothermal water during polymerization experiment under a) neutral pH of 6.5 and b) acidified to pH ~5.5 by sulfuric acid; and during adsorption experiment by c) D-50-1000AW silica gel and e) Mallinckrodt silica gel under neutral pH and by those silica gels under acidified pH condition (d and f, respectively). Solubility of amorphous silica in the presence of 0.6 M salt is added based on formula from Marshall (1980).

The different concentration of SiO_2 (M) and SiO_2 (T) at the initial state indicates that polymerization of silicic acid has already occurred prior to the experiment. The difference value between SiO_2 (T) and SiO_2 (M) indicates the existence of polysilicic acid (SiO_2 (P)). As depicted in the graph, the initial SiO_2 (P) concentration is higher under neutral pH (327.3 ppm) than acidified pH (135.0 ppm). This indicates that silicic acid has polymerized prior to each experiment along brine pipeline connecting separator and air-flasher tank and during flashing in air-flasher. The higher amount of SiO_2 (P) at initial condition under neutral pH than under acidified pH indicates that the rate of polymerization was faster at higher pH condition. Meanwhile, the initial SiO_2 (T) concentration under neutral pH (1,161.6 ppm) is lower than that under acidified pH (1,276.1 ppm) which indicates some silicic acid had been precipitated prior to polymerization experiment under neutral pH.

The concentration of SiO_2 (M) during adsorption experiment on D-50-100AW and Mallinckrodt silica gel under neutral pH condition (Figure 4c and 4e, respectively) decreased from 834.3 to 329.7 ppm and from 834.3 to 281.1 ppm, while SiO_2 (T) concentration decreased from 1,161.6 to 325.3 ppm and from 1,161.6 to 274.0 ppm, respectively. Total Fe concentration decreased from 2.06 to 0 ppm during D-50-1000AW silica gel adsorption experiment under neutral pH condition, while it was decreased from 2.06 to 0.01 ppm during Mallinckrodt silica gel adsorption experiment. The decreasing concentration of those constituents during adsorption experiments shows similar pattern with that during polymerization experiment suggesting that those silica gels gave a negligible effect to the polymerization and precipitation of silicic acid under neutral pH.

The SiO_2 (T) concentration slightly decreased from 1,255.8 to 1,014.8 ppm during D-50-1000AW silica gel adsorption experiment under acidified pH condition (Figure 4d), while it decreased from 1,276.1 to 861.9 ppm during Mallinckrodt silica gel adsorption experiment (Figure 4f). The different final concentration of SiO2 (T) during adsorption experiment and polymerization experiment suggests the occurrence of adsorption of silicic acid onto silica gel, where larger specific surface area of silica gel adsorbed more silicic acid from geothermal water. However, total Fe concentration was maintained at high level during adsorption experiment under acidified pH condition suggesting that Fe did not incorporate in the interaction of silica gel with silicic acid in geothermal water.

3.2 Mineralogical characteristic

XRD pattern of silica scale deposited on copper plates depicts that the main component is amorphous silica (Figure 5). This is shown by the scattering band at around 2theta = 22-23° (Manceau et al., 1995). In addition to the characteristic of amorphous silica, some

interesting peaks are found especially in silica scale deposited for a longer duration and under different pH conditions. Peaks of magnetite is found at 35.5° and 62.8°. The scale is also attributed with 2 strongest peaks of cronstedtite ($Fe^{2+}_2Fe^{3+}_2SiO_5(OH)_4$) at 12.5° and 25.1°, where both are probably coincide with the first and third peak of chamosite ($Fe^{2+}_3Mg_{1.5}AlFe^{3+}_{0.5}Si_3AlO_{12}(OH)_6$) at 12.5° and 25.2°. The second peak of chamosite at 18.9° is probably obstructed by the scattering pattern of amorphous silica while the fourth peak appears at 6.3°.

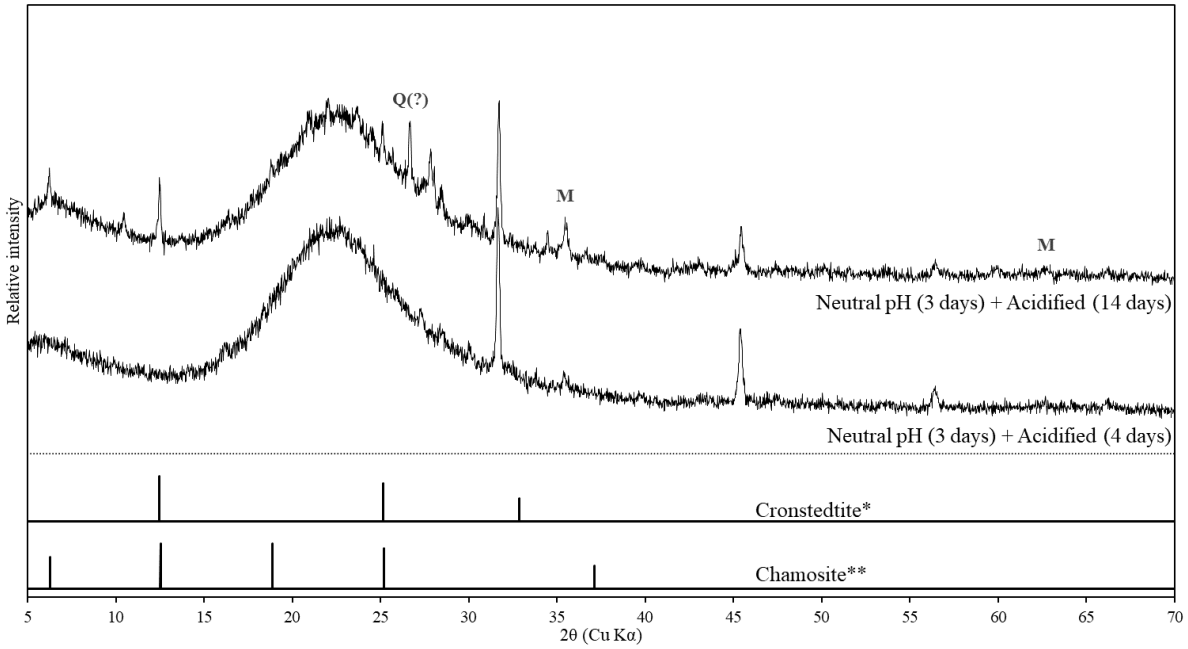

Figure 5: XRD patter of silica scale deposited on copper plate at open canal system (Q=quartz, M=magnetite) (* = from Anthony et al., 2019; ** = from Vassileva and Bonev, 2002).

3.3 Metal contents of the scale

The concentration of metals in the siliceous deposit on the copper plate test are presented in Table 2. Siliceous deposit resulted in 1 day experiment under only neutral pH contains Fe 0.148 wt.%, Al 0.011 wt.% and Mg 0.006 wt.%. The concentration significantly increased when pH was decreased, Fe concentration increased to 0.348 wt.%, while Mg and Al increased to 0.015 and 0.040 wt.% respectively after 3 days under neutral pH followed by 4 days under acidified condition. The longer the duration, Fe seems even more concentrated as well as Al. After 3 days under neutral pH conditions and followed by 14 days under acidified condition total Fe concentration in the siliceous deposit was as high as 0.813 wt.% while Al was 0.474 wt.% and Mg 0.126 wt.%.

Table 2: Metals concentration in the siliceous deposit on copper plate

Experiment duration and pH condition	Fe	Mg	Al
	(wt. %)		
1 day neutral	0.148	0.006	0.011
3 days neutral + 4 days acid	0.348	0.015	0.040
3 days neutral + 14 days acid	0.813	0.126	0.474

4. DISCUSSION

4.1 Polymerization and precipitation mechanism and the role of Fe

In this experiment, the initial concentrations of SiO_2 (T) and SiO_2 (M) at open canal are different under neutral pH condition. The difference between SiO_2 (T) and SiO_2 (M) indicates the existence of polysilicic acid (SiO_2 (P)) which is formed inside brine pipe feeding the air-flasher tank. The occurrence of SiO_2 (P) at initial condition makes the precipitation of silicic acid very rapid as the experiment began. The decrease of SiO2 (M) indicates the reaction among monosilicic acids (M-M reaction) to form polysilicic acid, as well as the interaction between monosilicic acid with existing polysilicic acid (M-P reaction) to make larger polysilicic acid. Meanwhile reaction among polysilicic acids (P-P reaction) is believed to occur as well, making the growth of polysilicic acid even faster. Under neutral pH condition all reactions (M-M, M-P, and P-P reaction) occurred simultaneously since the beginning of experiment resulting in a rapid deposition of silica which is indicated by the decrease of total silicic acid (SiO_2 (T)) concentration. On the other hand, the different concentration of SiO_2 (M) and SiO_2 (T) at initial condition under acidified pH is much less than that under neutral pH, which indicates lower concentration of SiO_2 (P) at initial condition. Acidification of geothermal water clearly suppresses both polymerization rate of SiO_2 (M) and growth rate of SiO_2 (P) which is indicated by the slow decrease of SiO_2 (M) and SiO_2 (T) concentration under acidified condition. Addition of sulfuric acid prevents the interaction among monosilicic acid by providing an excess of proton to stabilize monosilicic acid (H_4SiO_4) (Kitahara, 1960; Weres et al., 1981; and Tarutani, 1989).

Decrease of total Iron (Fe) concentration in geothermal water during the experiment clearly coincided with the decrease of SiO_2 (T) concentration. This signifies that Fe is incorporated with polysilicic acid in Dieng geothermal water and co-precipitated in silica scale. The idea is supported by XRD analysis result which shows the possible peaks of Fe-Si-O complex as cronstedtite and chamosite. The importance of Fe in the formation of silica scale in fact has been studied in the past decades (e.g. Rothbaum et al., 1979, Yokoyama

et al.,1980; Weres et al., 1981, Gallup and Reiff, 1991; Manceau et al., 1995; and Yokoyama et al., 1993). Rothbaum et al. (1979) and Weres et al. (1981) suggested that iron (ferric hydroxide) plays an important role as the nuclei in the formation of amorphous silicate from geothermal water, where decreasing pH will limit the number of nuclei available in the solution (Rothbaum et al., 1979). Furthermore, Weres et al. (1981) proposed Fe(II) as the most likely constituent to be incorporated in amorphous silica, followed by aluminum, magnesium and calcium. On the other hand, a study conducted by Yokoyama et al. (1980) showed that $Fe(OH)_3$ effectively adsorbed monosilicic acid and polymerized into polysilicic acid. The process works best under pH 9 and gradually becomes less effective by decreasing of pH. Meanwhile, Gunnlaugsson and Arnorsson (1982) has investigated the speciation of iron in geothermal water and concluded that at low temperature geothermal water (below 150 °C) iron exists predominantly as Fe^{2+} (ferrous iron), while at higher temperature $Fe(OH)_4^-$ (ferric iron) appears as the dominant species from the dissolution of iron-bearing minerals such as pyrite, marcasite, and pyrrhotite. Furthermore, MacKibben and Williams (1989) has studied that Fe^{2+}/Fe^{3+} ratio increase by the increase of salinity, where both can co-exist as chloride salts ($FeCl^+$ and $FeCl_2^+$, respectively).

Ferric ion (Fe-III) concentration was determined by spectrophotometrically analyzed the geothermal water after the addition of ferron (7-iodo-8-hydroxyquinoline-5-sulphonic acid) and pH adjustment to 5 in order to understand the speciation of iron in Dieng geothermal water (Yoe and Hall, 1937; Musha and Ogawa, 1959). As shown in Figure 6, ferron-reactive iron (Fe-R) or Fe(III) concentration is less than the concentration of total iron at the initial condition, which suggests that Fe exists as ferric species as well as other species. In addition, the species of Fe in geothermal water at the output of separator was also determined where total iron concentration is equal to ferric iron concentration which indicates that iron occurred as Fe(III) rather than Fe(II) prior to experiment at open canal. Therefore, the different concentration of total iron and ferron-reactive iron is more likely due to incorporation of ferric iron into polysilicic acid. The decrease of SiO_2 (M) and SiO_2 (T), as depicted in Figure 6, coincide with the decrease of ferron-reactive iron and total iron during polymerization experiment under neutral pH. This indicates that Fe incorporates into polysilicic acid in the early stage of polymerization reaction (M-M reaction) and possibly accelerates the polymerization reaction. This result is in agreement with the previous study by Yokoyama et al. (1980). Furthermore, the decrease of total iron concentration towards 0 ppm indicates that iron completely deposited along with the deposition of silica from Dieng geothermal water.

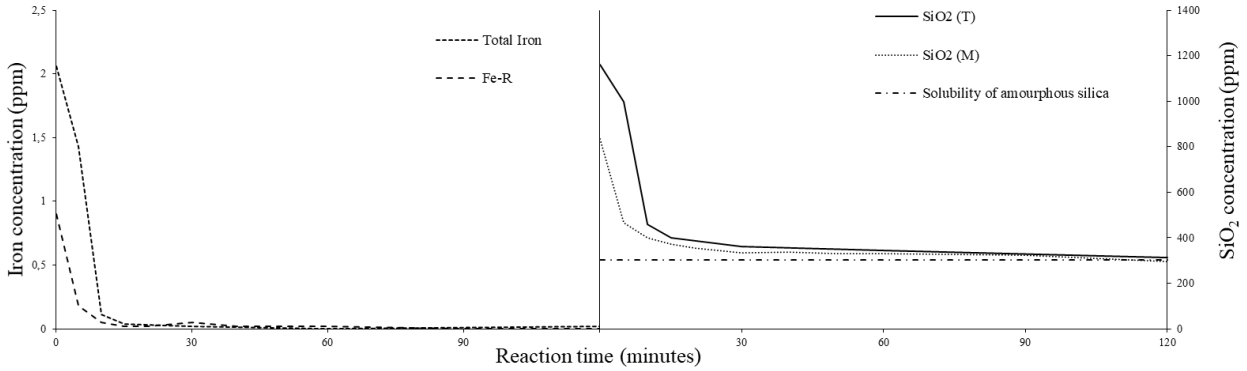

Figure 6: The change of total iron, ferron-reactive iron (Fe-R) or ferric (Fe-III) hydroxide, SiO_2 (M), and SiO_2 (T) in Dieng geothermal water during polymerization experiment under neutral pH condition.

In order to examine the effectivity of open canal, we demonstrated the polymerization experiment under acidified pH (operational condition) up to 4 hours to investigate the beginning of the precipitation of silicic acid (Figure 7). The result shows that both SiO_2 (T) and Fe started to decrease gradually after 60 minutes and reached 359.2 ppm and 0.76 ppm within 150 minutes, respectively. From this result, we can interpret that acidification may delay the precipitation of silicic acid in geothermal water by decreasing the growth rate of polysilicic acid. The fact that Fe was not completely removed from geothermal water when there is no polysilicic acid may suggest that under acidified condition Fe exist as ferric hydroxide species rather than incorporate in silicate. This result is in agreement with the previous studies (by Rothbaum et al., 1979, Weres et al., 1981, and Yokoyama et al., 1993) that acidification may limit the interaction of nuclei (ferric hydroxide) with silicic acid in the geothermal water.

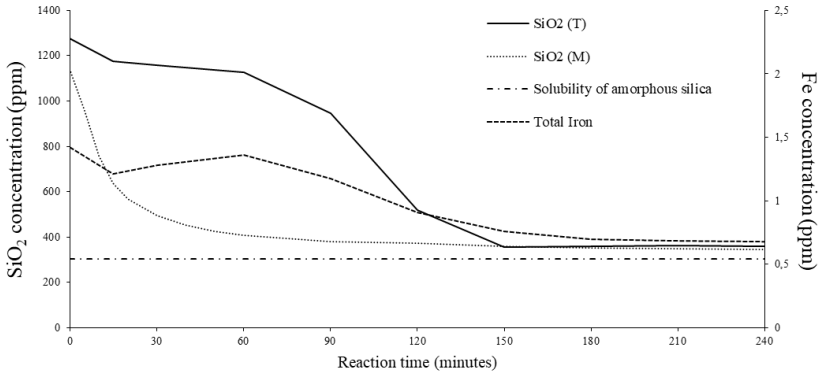

Figure 7: Change of silicic acid and Fe concentration in geothermal water during polymerization experiment extended to 4 hours under acidified pH.

In regards to the high concentration of Fe, Al, and Mg in the siliceous deposit especially in those which is deposited in a longer duration of acidified condition, a different source of Fe is suspected to increase its concentration. As shown in Figure 7 that the total concentration of dissolved Fe in geothermal water at initial condition under acidified pH remain same as that under neutral pH.

Furthermore, precipitation of dissolved Fe from geothermal water seems to be dependent on the precipitation of silicic acid. We suspect that the source of Fe and Al in the siliceous deposit on the copper plate tests was from colloidal iron oxide/hydroxide or iron sulfide. One possible colloidal iron oxide appears under x-ray diffraction observation as magnetite.

4.2 Stability of silica at initial brine condition

In addition to empiric data from onsite experiment, geochemical model is also constructed based on the actual chemical composition of Dieng geothermal water. Water samples are collected from two-phase pipe, brine pipe, and open canal. The redox condition is based on the knowledge of previous studies (e.g. Gallup, 1993 and McKibben and Eldridge, 1989) and is set to be from -500 mV to 1,000 mV, while pH is set to be from 3.0 to 9.0. Some minerals need to be suppressed from the model due to incompatible thermodynamic condition. Minerals included in the model are based on the previously found in geothermal scale (especially in Fe rich, high salinity, and high silica content geothermal water) such as amorphous silica, arsenopyrite, calcite, chalcopyrite, cronstedtite, $Fe(OH)_{2(ppd)}$, $Fe(OH)_{3(ppd)}$, $Fe_2(SO_4)_{3(C)}$, goethite, hematite, magnetite, nontronite-(Ca/K/Mg/Na), epidote, pyrite, and pyrrhotite (from McKibben and Williams, 1989; Gallup and Reiff, 1991; Gallup, 1993; Yokoyama et al, 1993; Manceau et al, 1995; Eggleton and Tilley, 1998). The oxidation states of Fe are set into Fe^{3+} based on spectrophotometry analysis by ferron addition method. Preliminary model of Fe speciation suggests that iron exists predominantly as ferric hydroxide ($Fe(OH)_2^+$) followed by ferric chloride ($FeCl_2^+$).

In the presence of Fe^{3+} as $Fe(OH)_2^+$ in geothermal water, stability of silica is highly controlled by Fe-Si-OH complex (see Figure 8). In this model, temperature and pressure were set to open canal initial temperature (100°C) and pressure (1 atm). This model support the idea of interaction of Fe with silicic acid in the precipitation of silicic acid in Dieng geothermal water. Again, the model agrees with the study by Yokoyama et al. (1980) which suggested that ferric hydroxide adsorbs monosilicic acid in geothermal water on which monosilicic acid polymerized to form polysilicic acid and further degree of polymerization. Even though they further explained that the interaction is more intense under pH 9 and gradually decrease by the decrease of pH, however the model suggest that even under weak to intermediate acid condition the interaction is still possible. Furthermore, it is important to note that interaction between Fe and silicic acid is best described by kinetic model rather than thermodynamic model (as depicted in Figure 8), but the model may help to understand the initial condition of geothermal water at which the interaction start to proceed.

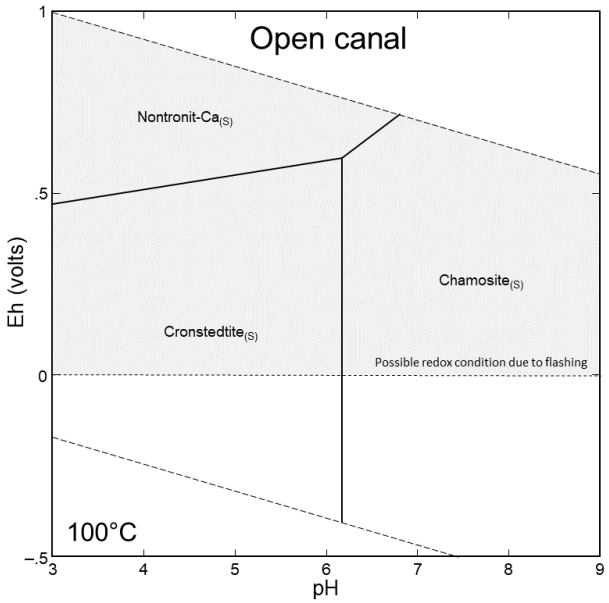

Figure 8: Eh-pH diagram of initial brine condition at open canal system Dieng geothermal power plant.

4.3 Interaction of silicic acid with silica scale

The adsorption experiment by silica gel was done to understand the interaction between silicic acid in geothermal water with silica scale (represented by silica gel). As shown in Figure 4, SiO_2 (M) decreased during polymerization experiment and adsorption experiment under neutral pH in a same rate. On the other hand, SiO_2 (T) decreased in a slower rate during adsorption experiment. Adsorption experiment by Mallinckrodt silica gel (having larger specific surface area) had a slightly slower deposition rate than that of D-50-1000AW silica gel. This may indicates that the larger surface are of silica gel, the slower the deposition rate. One possible reason is that silica gel may adsorb monosilicic acid from geothermal water, hence the M-P reaction during growth of polysilicic acid is somewhat limited by the presence of silica gel.

Decrease of SiO_2 (M) under acidified condition is somewhat slower during adsorption experiment than that during polymerization experiment, while in contrary, decrease of SiO_2 (T) is fairly faster during adsorption experiment. The slower SiO_2 (M) decrease during adsorption experiment may indicate the limited M-P reaction, while the faster decrease of SiO_2 (T) may indicate the adsorption of SiO_2 (P) onto silica gel. In addition, the decrease of SiO_2 (T) were not followed by the decrease of total Fe which suggest that the interaction between SiO_2 (P) with silica gel did not involve Fe in the process. The results suggest that the existed silica scale on open canal might interact with silicic acid and resulted in the growth of silica scale even under acidified pH condition.

5. CONCLUSION

Silica scale formed in Dieng geothermal power plant consists of mainly SiO_2 along with high concentration of Fe and Al. Contribution of Fe in the polymerization and precipitation of silica along open canal system was investigated and confrimed to play an important

role for the formation of silica scale at Dieng geothermal water. Under neutral pH, Fe and SiO_2 precipitate simultaneously and rapidly from geothermal water, while they remained high in geothermal water after acidification, indicating no precipitation occured. Furthermore, Fe seems to play a role in accelerating the polymerization of silicic acid especially under neutral pH condition. Addition of sulfuric acid to lower pH successfully slowed down the rate of polymerization, which results in the delay of precipitation of silicic acid, probably by two mechanisms: slowing down the reaction among monosilicic acid and limiting the interaction of ferric hydroxide with monosilicic acid. Through adsorption experiment we found that monosilicic acid may attach on the surface of silica gel (representing silica scale in pipeline) under neutral pH condition, while polysilicic acid seems to be adsorbed on silica gel under acidified condition even without contribution of Fe in the process.

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