Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Scaling potential analysis along production wellbore in Awibengkok Geothermal Field Indonesia

Gagas P. Utomo

Calsichem Consultancy, Jl. Malangbong AR C7 Bandung West Java, Indonesia 40291

gagasutomo@yahoo.com

Keywords: Mineral scaling, PHREEQC, saturation index, equilibrium phase

ABSTRACT

The combination of pressure and temperature drop with boiling and degassing contributes to mineral scaling formation in the geothermal wellbore. The formation of mineral scaling decreases the flow rate of geothermal wells by clogging boreholes and surface equipment. Since scaling remediation effort is highly dependent on the chemistry of geothermal water, a geochemical assessment is required to support it. This study aims to perform geochemical modeling to identify the potential and rate of scale formation in the Awibengkok Geothermal Field. An advection simulation is made using PHREEQC by utilizing published water chemistry and well pressure-temperature data. The result from the modeling shows the following at depth shallower than 1000 m: i) increase in species concentration due to boiling except for Na^{+}+K^{+} and Cl^{-}, ii) the drop in pH and saturation index (SI) of calcite, aragonite, and amorphous silica, and iii) calcite and quartz as potential scaling mineral determined by equilibrium phase calculation. Maintaining temperature between depth of 1000-0 m show that pH, SI of potential scaling mineral, and the amount of possible calcite precipitate can be controlled throughout the wellbore, while possible quartz precipitate is reduced with the maximum amount occurring at a depth of 800 m.

1. INTRODUCTION

Geothermal fields have the risk of being exposed to the problem of mineral scaling formation. The geochemical properties of geothermal water are generally in equilibrium with host rocks inside the reservoir's environment. However, water properties change as it moves up to the surface facilities with a drop in pressure and temperature. Processes such as boiling and degassing also promote an increase in dissolved species concentration and pH, respectively. The combination of these processes contributes to the formation of mineral scaling in the wellbore.

Mineral scaling problems decrease the flow rate of geothermal wells by clogging boreholes and surface equipment. Efforts are made to overcome this problem by various methods such as the use of inhibitors, well remediation, and production conditions adjustment (flowrate, pH. pressure, and temperature). The application of these methods is highly dependent on the water geochemistry of each field. Thus, a geochemical study is required to understand precisely the potential of scale formation to determine the optimal solution.

This study aims to assess the scaling potential present in Awibengkok geothermal field using the PHREEQC program (Parkhurst and Appelo, 2013). PHREEQC is a freeware that performs various aqueous geochemical calculations and is used to model reactions and geochemical processes. The extended llnl.dat thermodynamic database is used during simulation in this study better to predict the solubility of CO_2 in a higher-pressure environment. An advection modeling is made to calculate potential scaling minerals' solubility in the wellbore of a known production well. Water chemistry and well pressure and temperature from published work are used as input (Allis, 1999; Aprilina et al.,2015).

2. GEOLOGY

The Awibengkok geothermal field is the largest developed geothermal field in Indonesia, currently having an installed 377 MW electrical generation (Acuna et al., 2008). The Awibengkok geothermal system is located in a mountainous area with an elevation ranging from about 950-1500 meters above sea level. The geothermal reservoir is associated with young volcanism and intrusions in a highland area southwest of Salak volcano and east of the Cianten caldera (Aprilina et al., 2015). The oldest rocks are mainly shallow-marine carbonates and epiclastic sediments (mudstones and sandstones containing abundant volcanic ash and lithic debris) (Stimac et al., 2008). Bojongmanik formation (Figure 1) from Middle Miocene overlies these rocks and comprises sandstone, pumiceous tuff, marl, limestone, and claystone. This formation is overlain by tuff and breccia formed in Late Miocene (Efendi & Hermanto, 1998). These sedimentary units are overlain unconformably volcanics units formed during Quarternary.

The Oldest volcanic units are formed during the Early Pleistocene and are composed of undifferentiated volcanic rocks, volcanics breccia, and volcanic lava (Figure 1) (Efendi & Hermanto, 1998). Salak volcanics formed during the Middle to Late Pleistocene comprise tuff, lahar, tuffaceous breccia, and andesitic basaltic lava. The products of Salak volcanics are Cianten caldera and Salak volcano ((Figure 1). Andesitic lava of Endut-Perbakti volcanics forms the youngest deposits in the area (Efendi & Hermanto, 1998). Volcanoes, namely Perbakti, Gagak, Endut, and Awibengkok, are included in this unit.

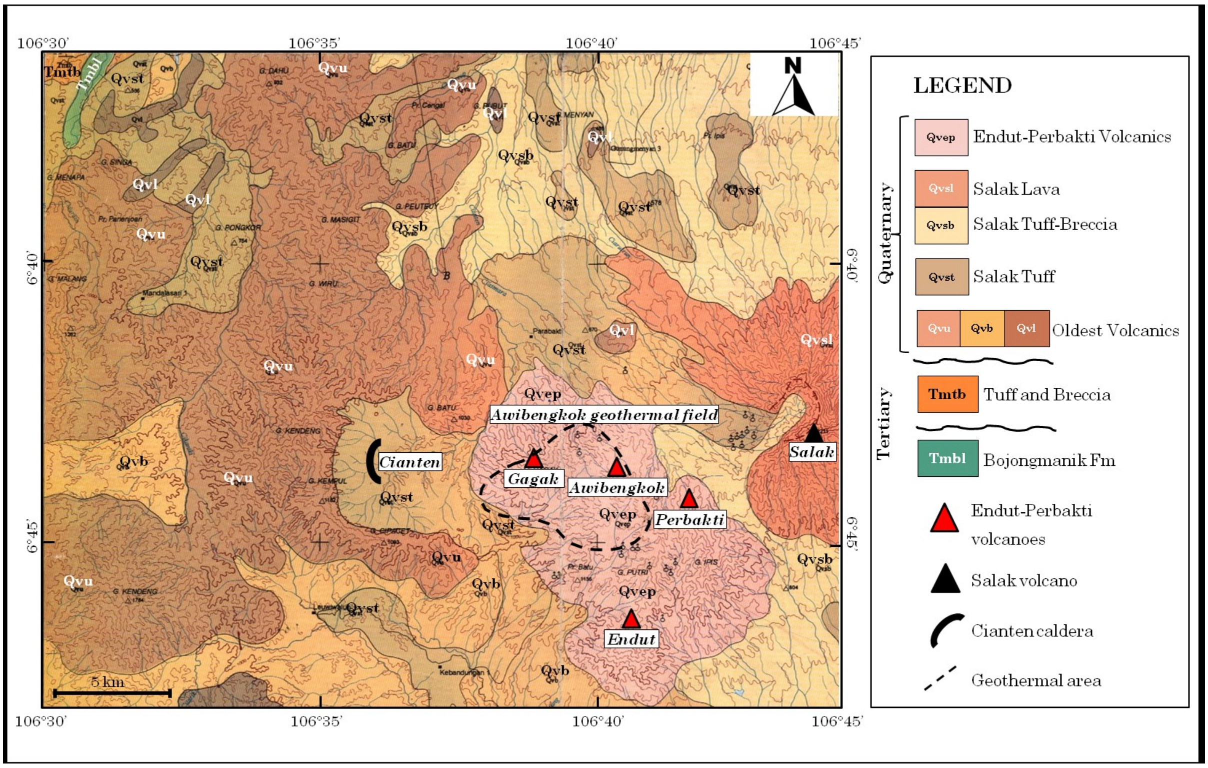

Figure 1: Geologic map of Awibengkok geothermal field (Efendi & Hermanto, 1998) showing major volcanoes.

3. WELL WATER CHEMISTRY

Awibengkok field is divided into four sectors based on the fluid chemistry, temperature, and flow patterns: Western, Central, Eastern, and Far Eastern Cells, bounded by faults (Stimac et al., 2008). Western Cell hosts 2 wells, Central Cell 5 wells, Eastern and Far Eastern Cells host 4 and 2 wells, respectively. Central Cell has the highest Cl concentration and the lowest gas content compared to the other cells. The highest temperature is measured in the Western Cell, followed by Central, Eastern, and Far Eastern Cells. The chemistry of well waters is also presented as Schoeller diagram in Figure 2 Awi 1-2 RD from the eastern cell are taken from the study of Allis (1999), which is classified as alkali-chloride (Na+K-Cl) water.

Table 1. Well water chemistry of Awibengkok geothermal field (concentration in ppm) (Allis, 1999)

ID	T (°C)	pH	K	Na	Ca	Mg	SiO_2	HCO_3	SO_4	Cl	TDS
Awi 1-2 RD	-	6.9	630	3680	227	0.7	498	96.2	23.6	6700	12116

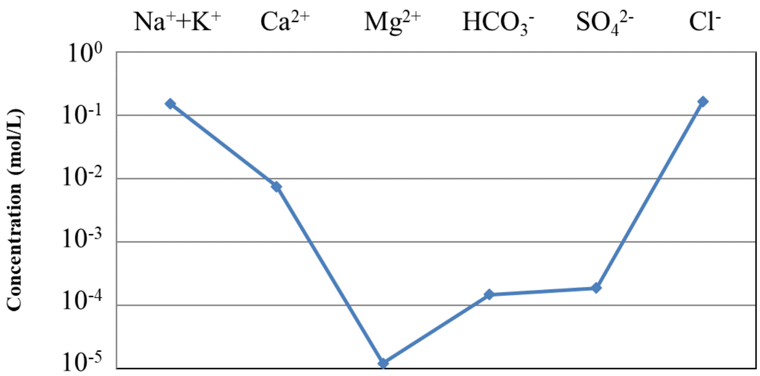

Figure 2: Schoeller diagram of well waters in Awibengkok field

4. GEOCHEMICAL MODELING

In this study, the change of water geochemistry along production wellbore is modeled. The previous study's pressure and temperature gradient (Aprlina et al., 2015) is assigned to the modeled wellbore (See Figure 3). The model consists of 22 cells with descending pressure and temperature condition from the well bottom to the well surface. Given the Well water chemistry and amount of non-condensable gas (NCG) from Allis (1999) is used as input. The partial pressure of NCG is assigned as 90% CO_2, 9%H_2S, 1% CH_4, 1% N_2. Well water and NCG are mixed to recreate the initial geothermal water chemistry inside the reservoirs. Potential scaling minerals (calcite, aragonite, chalcedony, amorphous silica, and quartz) are assigned to the simulation.

The geochemical calculation is done using the PHREEQC program using speciation and solubility calculation and equilibrium modeling. PHREEQC is a freeware that performs a wide variety of aqueous geochemical calculations and is used to model reactions and geochemical processes (Parkhurst and Appelo, 2013). The extended llnl.dat thermodynamic database is used during simulation in this study better to predict the solubility of CO_2 in a higher-pressure environment. Firstly, one liter of the simulated reservoir water is equilibrated with the well bottom's pressure and temperature. This equilibrated water is shifted and further reacted with the next cell with the lower pressure and temperature condition.

The change of geochemical parameter (pH, saturation index, and equilibrium phase) from each cell is evaluated to assess scaling potential at a specified depth. Saturation index (SI) is utilized to determine the water's saturation state to a particular mineral based on the following formula $SI = log\,(\frac{IAP}{Ksp})$. IAP and Ksp are the ion activity product of a mineral's dissolved ions (e.g., Ca^{2+} and CO_3^{2-} for calcite) and the mineral's solubility product. Water is classified as equilibrium with a particular mineral when its saturation index value is zero ($SI = 0$). Oversaturation and undersaturation are defined by positive ($SI > 0$) and negative ($SI < 0$) values, respectively. The equilibrium phase calculates the amount of mineral that can be precipitated from the existing cell condition.

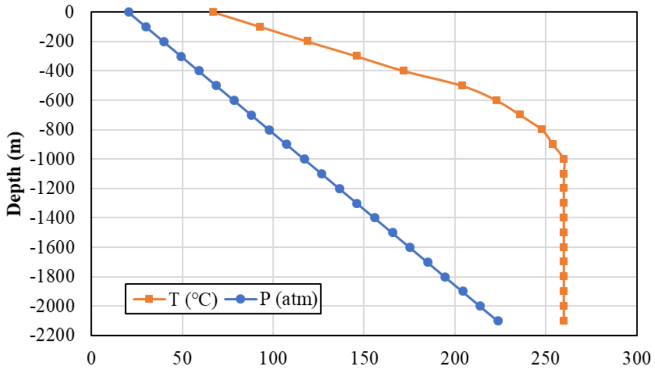

Figure 3: Temperature and pressure of well based on (Aprilina et al., 2015)

5. RESULT AND DISCUSSION

The modeling shows that: i) the concentration of Mg2+ increases significantly, ii) while a slight increase of Ca^{2+}, HCO_3^- and SO_4^{2-} is observed at a depth above 1000 m (Figure 4). The concentration of Na^++K^+ and Cl^- seem to be constant along the wellbore. The concentration increase of some species is most likely due to degassing caused by boiling resulting from pressure and temperature drop at these depths. This observation is also supported by the drop in pH observed at a depth above 1000 meters. A drop in saturation index (SI) calcite, aragonite, and amorphous silica is observed as the water approaches the surface. A slight decrease in chalcedony SI is seen, while quartz SI is observed unchanged with decreasing pressure and temperature.

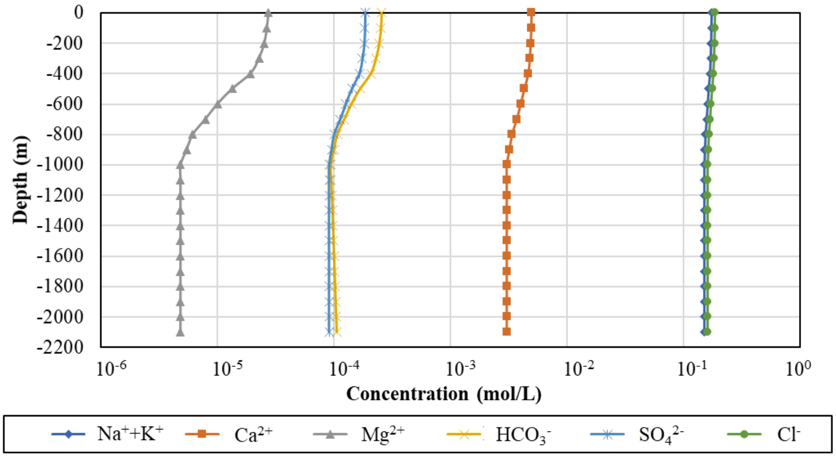

Figure 4: Change of dissolved species concentration along the wellbore

The equilibrium phase simulation shows that the potential scaling minerals are calcite and quartz, shown by the amount of mineral required for the equilibrium condition to reach. The maximum amount of calcite that may be precipitated per liter of water (0.000661 mol) is observed at the well bottom. This amount is reduced to absent at a depth above 400 m. In terms of quartz, a constant amount (0.0017 mol) of possible quartz precipitate is observed from the well bottom to the depth of 1000 m. At shallower depth, the quartz's equilibrium phase fluctuated with the maximum precipitate reaching 0.025 mol per liter at 400 m depth.

This result suggested that scaling potential most likely occurs in depth shallower than 1000 m. A further simulation is conducted to reveal whether pressure or temperature has the most noticeable impact on the scaling formation potential. Two simulations are conducted: 1) pressure is kept constant for 97.8 atm with decreasing temperature (P batch), and 2) temperature is kept constant for 248℃ with decreasing pressure (T batch) between 1000 m to surface. These simulations are presented based on pH, SI, and equilibrium phase vs. depth graph (Figure 5, 6, 7). The P batch shows no significant difference from the original simulation, while the contrary result is observed from the T batch.

The T batch result shows that pH and the saturation index of all potential minerals are maintained constant from well bottom until surface (Figure 5 and 6). In terms of equilibrium phases, the precipitation potential of calcite and quartz show the following differences: i) The amount of possible calcite precipitate is seen constant throughout the wellbore, ii) this observation contradicts the original simulation in which calcite precipitate is absent at depth above 400 m, iii) the amount of possible quartz precipitate is significantly reduced at a depth above 1000 m with the maximum amount detected at a depth of 800 m (Figure 7). These observations suggest that quartz has a more considerable potential to precipitate. The scaling prevention procedure is most required at a depth above 1000 m, focusing on the 800 m depth.

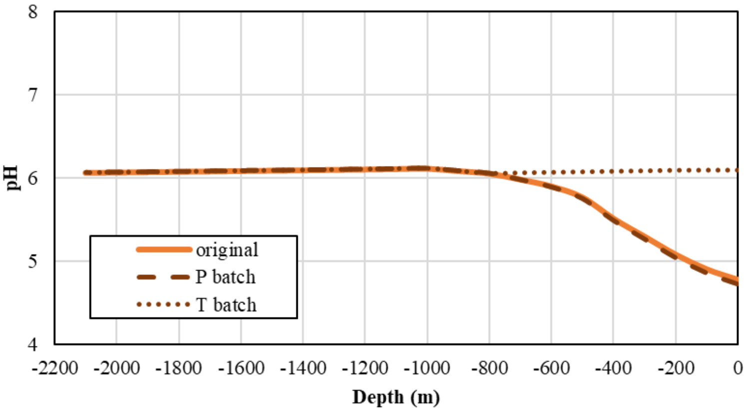

Figure 5: Change of pH along wellbore from three simulations (original, P batch, and T batch)

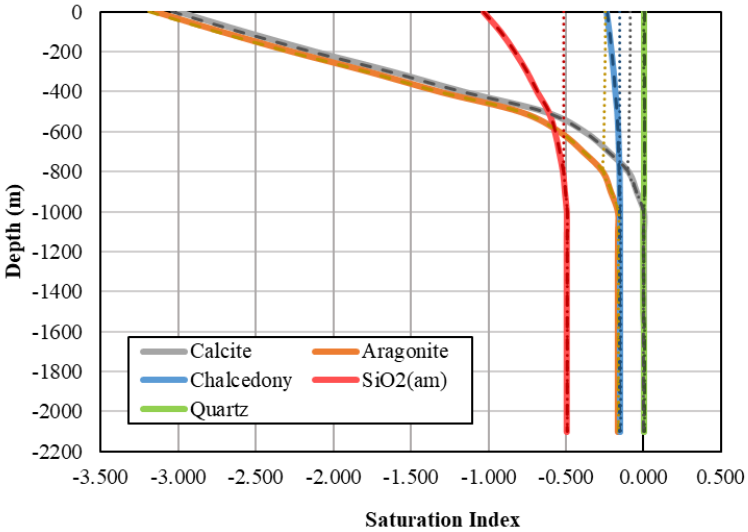

Figure 6: Change of Saturation Index of potential scaling mineral along the wellbore. Dashed lines show P batch, T batch is shown by dotted lines.

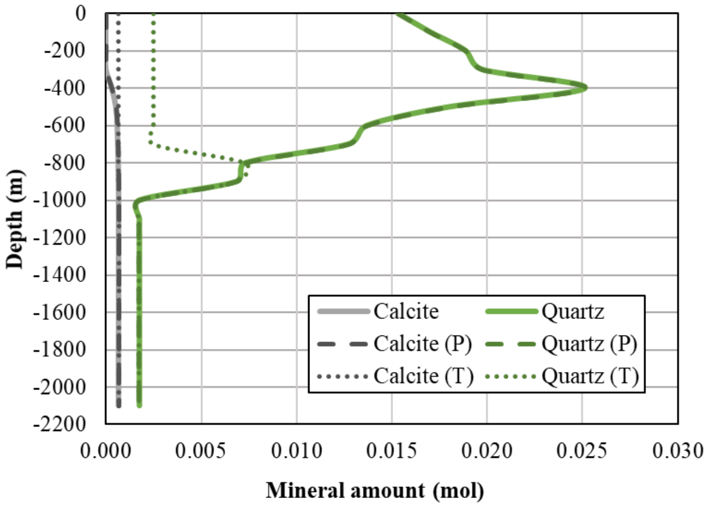

Figure 7: Change of equilibrium phase of calcite and quartz along the wellbore. (P): P batch, (T): T batch

5. CONCLUSION

Geothermal fields have the risk of being exposed to the problem of calcite and silica scale formation. Processes such as boiling and degassing also promote the increase in dissolved species concentration and rise in pH, contributing to the formation of mineral scale in the wellbore. A geochemical study is conducted to understand the potential for scale formation so that the optimal solution can be determined. The change of water geochemistry along the production wellbore is modeled by forming 22 cells with descending pressure and temperature condition from the well bottom to the well surface. Published well water chemistry and amount of non-condensable gas (NCG) assigned as inputs.

The result from the modeling shows: i) increase in dissolved species except for Na^++K^+ and Cl^- at a depth above 1000 m due to degassing from boiling, ii) the drop in pH and saturation index (SI) of calcite, aragonite, and amorphous silica as the water approaches the surface, iii) the potential scaling minerals are calcite and quartz determined from equilibrium phase calculation at a depth shallower than 1000 m. Two additional simulations are conducted, with the P batch result showing no significant difference from the original simulation. Results from the T batch show that pH, SI of potential scaling mineral, and the amount of possible calcite precipitate is seen constant throughout the wellbore, while possible quartz precipitate is reduced with the maximum amount occurring at depth 800 m.

REFERENCES

Acuna, J.A., Stimac, J., Sirad-Azwar, L. & Pasikki, R.G.: Reservoir management at Awibengkok geothermal field, West Java, Indonesia. *Geothermics*, 37, pp.332-46 (2008).

Allis, R.G.: Present day hydrothermal conditions in the vicinity of AWI 1-2, Awibengkok Geothermal Field, Indonesia. *Geothermal Resources Council Transactions*, 23, pp.3-8, (1999).

Aprilina, N.V. et al.: Geologic Modeling Workflow for Volcanic Hosted Geothermal Reservoirs: Case Study from Salak Geothermal Field. *Proceedings,* World Geothermal Congress 2015. Melbourne, Australia (2015).

Efendi, K. & Hermanto, B.: Geological Map of the Bogor Quadrangle, Jawa. *Geologic map.* Bandung: Geological Research and Development Centre, (1998).

Parkhurst DL, Appelo CAJ.: Description of input and examples for PHREEQC version 3-A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. *U.S. Geological Survey Open-File Report* (2013).

Stimac, J., Nordquist, G., Suminar, A. & Sirad-Azwar, L.: An overview of the Awibengkok geothermal system, Indonesia. *Geothermics*, 37, pp.300-31, (2008).