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Production Capacity Optimization By Silica Crust Analysis "TB-001" and "TB-002" Wells Sorik Marapi Geothermal Field

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ABSTRACT

The Sorik Marapi located in Mandailing Natal Regency, North Sumatra. Silica scale production wells "TB-001" and "TB-002" makes pipe diameter smaller, inhibits fluid flow, reduces energy output, and increases cost of cleaning even replacing pipes. The research expected to produce efforts to prevent silica scale thus production capacity optimized. Method used is Silica Saturation Index (SSI) with amorphous and quartz silica types. Temperature and pressure are important where appropriate settings can minimize silica scale. Study focused on the wellhead and separator part of the well. Furthermore, comprehensive feasibility evaluation of production well was conducted. Cap rock smectite - hematite mineral about 20° - 240°C and reservoir illite - epidote mineral about 240° - 340°C. Geothermal fluid is dominated by chloride water. Both wells have the potential silica scale in separator with SSI >1 and not in wellhead with SSI<1. The treatment to prevent the silica scale is to use hydrofluoric acid (HF) solution with concentration of 15% and immersion time of 15 minutes, where the effectiveness value is about 46-47%.

Keywords: geothermal; production wells; silica crust; sorik marapi; SSI

I. INTRODUCTION

Energy is one of the primary necessities for humans to support various activities. Indonesia, as a country rich in resources, including energy resources, has geothermal energy that needs to be optimized. Geothermal can serve as an alternative to fossil fuels, which are increasingly depleting. Geographically, Sumatra is located at the convergence of the Eurasian continental plate and the Indo-Australian oceanic plate. This positioning results in a series of volcanic pathways along the island of Sumatra, making it one of the islands with significant potential for geothermal development (Barber, 2005).

Indonesia has enormous potential, holding 40% of the world's geothermal potential, with reserve potential estimated at 25,300 MWe; around 2,000 MWe has been successfully developed into electricity. The potential in Sumatra is estimated to be about 13,420 MWe. Sorik Marapi has a potential of 245 MWe. Currently, the installed capacity is 20 MWe for Unit I and 30 MWe for Unit II (Jasmita, 2020). Therefore, further detailed research is needed to optimize geothermal energy in this area.

In geothermal operational activities, many issues often arise, one of which is the deposition of silica scale in production well pipes. This causes the pipe diameter to decrease and hinders fluid flow, resulting in long-term impacts that may require pipe replacement. Unobstructed pipes will lead to more optimal steam production and electricity generation (Ciptadi, 2001). Therefore, this study analyzes the potential for silica scale blockage in the production wells "TB-001" and "TB-002," specifically at the wellhead and separator as the initial fluid pathways to the turbine. It also provides recommendations for minimizing such blockages. Wells "TB-001" and "TB-002" were chosen because silica scale was found in the pipes of both wells, making them less efficient in delivering the production steam fluid flow compared to other wells.

For mitigation and prevention, until now, chemical solutions of HCl and H2SO4, salinity control, and partial pipe cutting are still used. As an innovation, researchers recommend using the concept of injecting Hydrofluoride (HF) solution to lower the pH of the fluid combined with the Silica Saturation Index (SSI) method. Of course, when compared to the use of other chemical solutions, HF is more environmentally friendly, easy to obtain, reacts quickly to silica, and is economical. However, the use of Hydrofluoride solution must be adjusted in terms of concentration and immersion time so as not to produce excessive corrosion in the production pipe, which can reduce the life time of the pipe.

1.1. Study Area

The study area is located in Puncak Sorik Marapi District, Mandailing Natal Regency, North Sumatera Province (Fig.1) and coordinates 0°41'11.72”S and 99°32'13.09”E UTM 47. This area is located on the northeast side of the lower Sorik Marapi mountain and on the main route of the Sumatran Fault System (SFS). The Sorik Marapi Geothermal WKP covers an area of 629 km². The Sorik Marapi field is one of the fields currently actively operating in Indonesia. Sorik Marapi located between two geothermal fields that are being developed, namely the Sarulla field and the Muara Labuh field (Rezky, 2015)

The location of this area is ±350 km from Medan City as the capital of North Sumatra and takes ±12 hours by car. Sorik Marapi located in the southern part of Medan City so the direction of travel is south from Medan City through several other cities such as Berastagi, Kabanjahe, Sibolga, and Padang Sidempuan. During the journey, we will be treated to beautiful and pristine views, and we will also have the opportunity to see one of North Sumatra's icons, the Toba Caldera, recognized as a UNESCO geoheritage site.

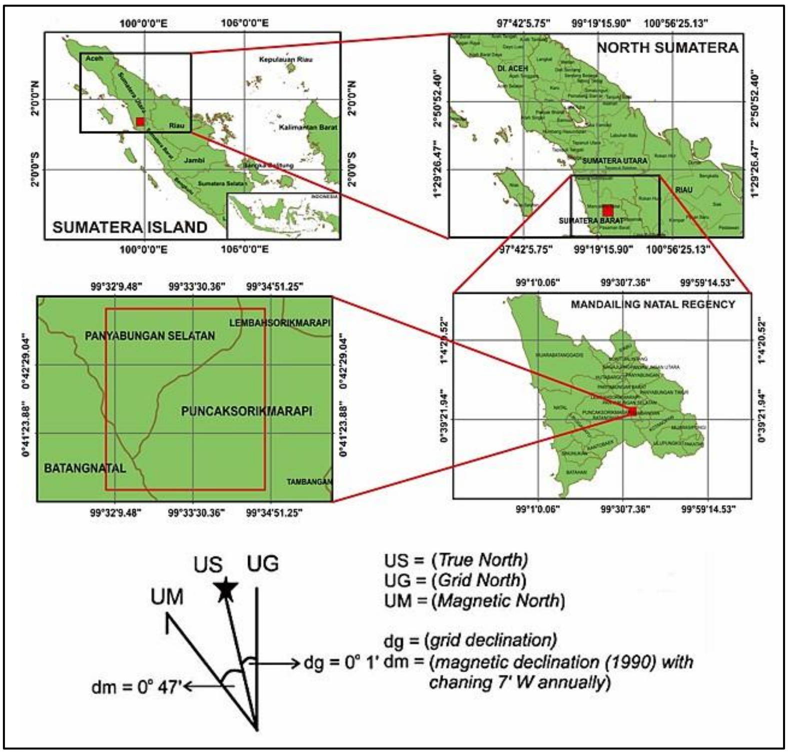

Figure 1. Overview Of The Study Area

1.2. Geological Setting of The Study Area

Sorik Marapi Geothermal Field is consist of two types morphology, volcanic and structural, which located in Penyabungan graben as part of the Sumatran fault. Mount Sorik Marapi is ± 15 km northwest of Sumatran fault and is adjacent to magmatic arc of Sumatra Island, namely Bukit Barisan Mountains. In general, geology of Sorik Marapi is composed of Tertiary and Quaternary volcanic rocks (Hochstein, 2000). Tertiary volcanics have the characteristics of dacitic to rhyolitic (acidic) rocks and Quaternary volcanics of andesitic to dacitic (intermediate - acidic) rocks. Tertiary volcanic products originate from the eruption Mount Maninjau in West Sumatra which produces morphology of the Maninjau Caldera. On the other hand, Quaternary volcanic products originate from the eruption Mount Sorik Marapi in North Sumatra which is still active until now (Azizi, 2020).

Based on reinterpretation, locally research area consists of 4 rock units, dacite lava, alternating andesite lava and dacite tuff, alteration dacite tuff and rhyolite tuff, and metamorphic basement. Sorik Marapi located in the Julurayeu Formation which was deposited in a fluvial to littoral environment. Lithology of Julurayeu Formation is clay and conglomerate at the bottom which increases to soft tuffaceous sandstone and volcanic rocks towards the top. Thickness of this formation is 400-600 m. The basement rock is in the form of Mesozoic to Paleozoic metasediments intruded by plutonic rocks (Jasmita, 2020).

The geological structure at location is part of Sumatran fault system. As known, Sumatra fault (Semangko) is a fault with a right horizontal movement orientation (dextral) in NW - SE direction. In addition, there is also a normal/downward fault that produces a depression zone forming a graben where the high areas in the southwest and northeast. The normal/downward fault will be a medium for magma to move towards to surface and produce the morphology of Mount Sorik Marapi (Barber, 2005).

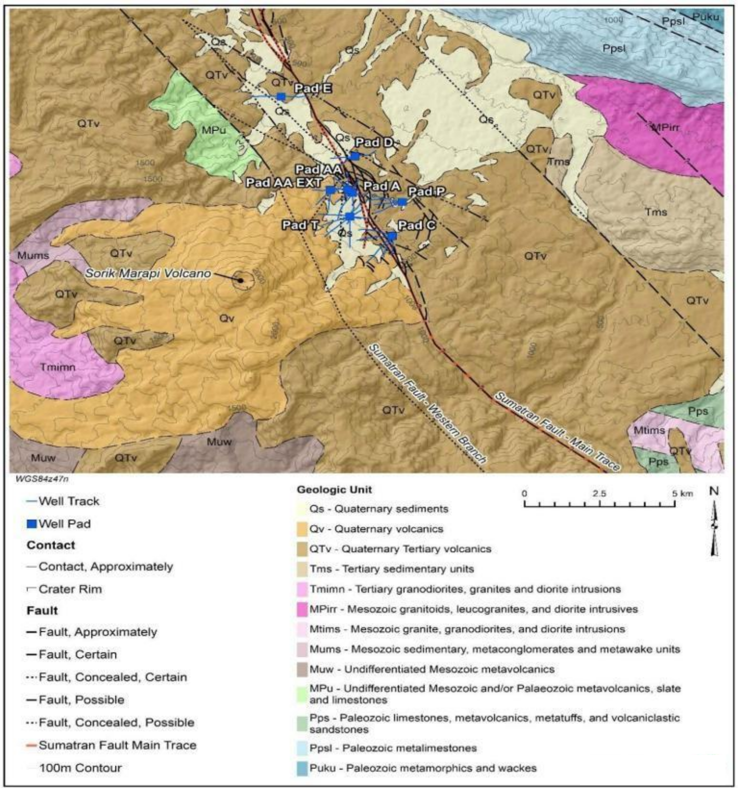

Figure 2. Overview Of The Geological Setting of The Study Area

II. METHODS

This study uses a combination of primary and secondary data. Figure 3 shows the research flow starting from the data collection stage, processing and analysis stage, output stage, and conclusion stage. The methods used to analyze silica crust deposits are fluid geochemistry and Silica Saturation Index (SSI) calculation. The calculation of the Silica Saturation Index (SSI) in this study is performed at the wellhead and separator, as these are considered the initial pathways for geothermal fluid entry. If the silica potential can be controlled at this early phase, it will help reduce the impact of silica scale in other areas. For prevention, researchers recommend to injection of hydrofluoric acid (HF) at specific concentrations and immersion times tailored to field conditions, hydrofluoric acid (HF) is being introduced as a new method at the Sorik Marapi Geothermal Field for managing silica scale. This acid solution was selected due to its cost-effectiveness, ease of availability, low environmental impact, and rapid reaction with silica. Additionally, it saves operational costs and time since there is no need to cut or replace pipes affected by silica scale. The effectiveness of hydrofluoric acid (HF) injection ranges from 46% to 47%, which is categorized as efficient for mitigation silica scale in production pipes.

2.1. Preliminary Stages

This stage is an initial activity to determine the research topic to be studied, search for and determine the research area, and conduct a literature study of research in related areas by previous researchers. Literature studies are conducted to determine the conditions of the research area before carrying out data collection, processing, and analysis activities to support research.

2.2. Data Collection

This stage aims to obtain data descriptively and systematically. With the note that the discussion of this study is emphasized on the analysis of Silica crust deposits on production well pipes. This stage is also to find primary data that is expected to complement and detail previous researchers. The data required includes:

1. Well Trajectory Data
    - Wellhead & Separator Pressure (barg)
    - Wellhead & Separator Temperature (C)
    - Silica Wellhead & Separator Concentration (ppm)
    - Chloride Wellhead & Separator Concentration (ppm)
    - Silica Density (gr/inch^3)
    - Pipe Diameter (inch)
2. Geology Data
3. Mud Log Data
4. Fluid Geochemical Data
    - Silica & Chloride Reservoir Concentration (ppm)
    - Reservoir Water & Vapor Entalphy (kJ/kg)
    - Separator Water Entalphy (kJ/kg)
    - Chemical Compounds (Cl-SO4-HCO3-B-Li-Na-K-Mg)

2.3. Data Processing and Analysis

The stage where the data obtained will be reprocessed and a detailed analysis will be carried out. Data processing uses calculation formulas accompanied by diagrams, models, and graphs. The calculations include corrections to the chemical composition of water, steam fractions, silica and chloride concentrations, the Chen Marshall equation, and the Silica Saturation Index (SSI). In addition, several analyses were also carried out including mud logs, mineral geothermometers, salinity, temperature, quartz solubility and amorphous silica (Sofyan, 2021). Data processing and analysis were carried out at the wellhead and separator. Finally, to emphasize the research, a comprehensive feasibility evaluation was carried out on the well so that researchers could provide recommendations regarding the well pipe settings so that they could minimize silica crust deposits for production optimization.

1) Fluid geochemical analysis: provides information on the results of the analysis of the composition of anions and cations of water from research well samples. The geochemical analysis of water in this study was carried out by utilizing the following diagrams:
    - Na – K – Mg: to determine fluid temperature
    - C1 – SO4 – HCO3 : to determine fluid type
    - C1 – Li – B : to determine fluid source
2) Silica crust deposition analysis: conducted based on temperature and pressure data at the wellhead and separator when taking fluid samples. This activity is conducted to determine the amount of Silica crust deposition, the speed of Silica crust formation, and the length of time the pipe is blocked by Silica crust in both production wells in the research area. In interpreting the presence of silica crust deposition through the Silica Saturation Index (SSI) method (Fournier, 1985)

$$\text{SSI} = \frac{Silica\ Concentration}{Silica\ Solubility} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.4. Output Result and Conclusion

This stage is the result of data processing and analysis that has been validated and declared appropriate. The expected output results include alteration zone models and cross-sections, geothermometer charts, Cl-SO4-HCO3/Cl-B-Li/Na-K-Mg diagram charts, vapor fraction values, fluid characteristics, Silica Saturation Index (SSI), formation rate (inch/year), blockage time (years), feasibility evaluation results, and conceptual models. To further clarify the output results, the researcher also made a detailed discussion of each output result. After obtaining the calculation results, the potential for silica crust deposits can be classified as follows (Fournier, 1985):

- If the SSI value > 1, then the fluid is in a very silica saturated state (supersaturated) and has the potential to form silica scale deposits.
- If the SSI value = 1, then the fluid is in a silica saturated state and has the potential to form silica scale deposits.
- If the SSI value < 1, then the fluid is in an undersaturated state and has no potential for the formation of silica scale deposits

The conclusion contains information about the summary of the research results and the researcher's recommendations. This stage must be able to answer 5W + 1H which consists of what the research is about, where the research takes place, when the research is carried out, why the research can take place, who are the parties involved in the research, and how the process takes place in the research. Therefore, this paper is made based on valid data that has been collected, not based on the researcher's imagination.

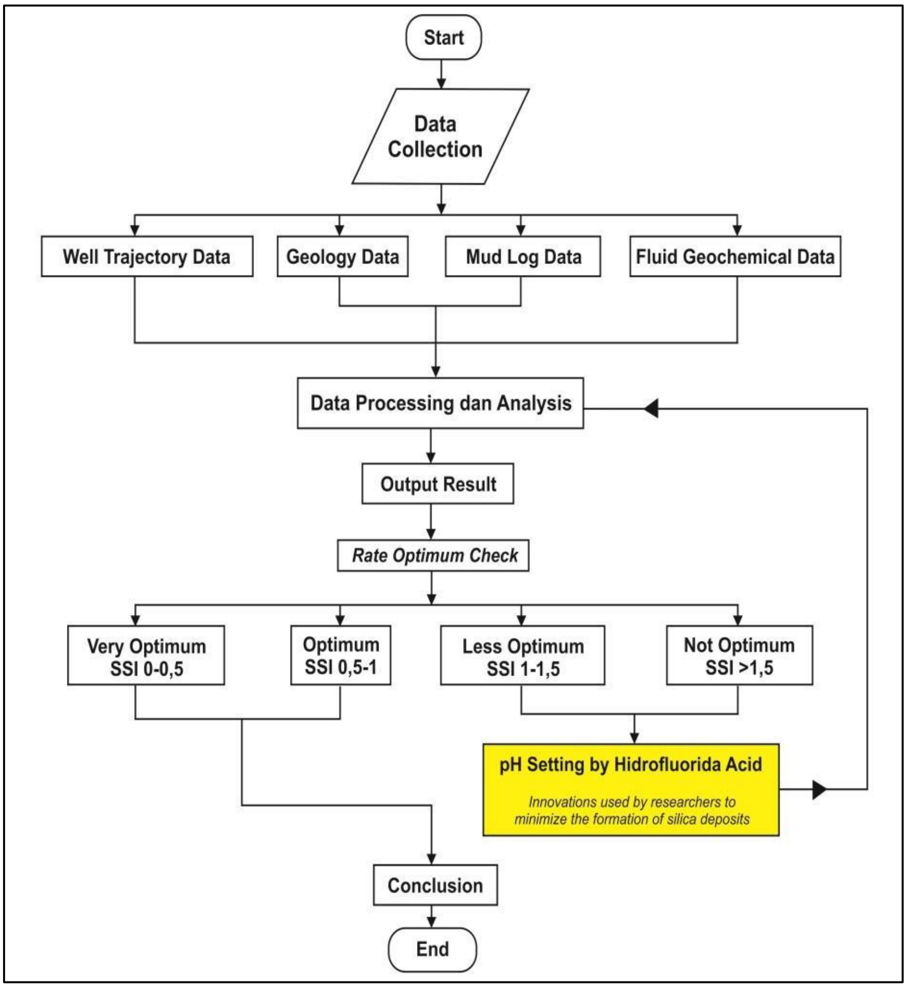

Figure 3. Flowchart Of The Study

III. RESULTS AND DISCUSSION

Data processing and analysis have been carried out using fluid geochemistry and Silica Saturation Index (SSI) methods with a calculation formula approach. The results obtained have been validated and are in accordance with the facts in the field. Researchers will describe the results of processing and analysis that describe the latest conditions of the Sorik Marapi Field related to silica crust as follows

3.1. Results of Subsurface Mineral Assemblage Zone Analysis

Geochemistry aims to group geothermal fluids based on the ratio of elements and their classification, and to obtain chemical data on fluids and gases, as well as other elements contained in geothermal manifestations so that the type of fluid, upflow zone, and outflow zone in the geothermal system and its flow direction can be determined. In this study, the chemical data used is water chemical data from geothermal manifestations and wells processed using geoindicators from each ratio of water chemical elements, in addition to stable isotope analysis (Hendri, 2021). This will inform the conditions of the reservoir, flow and environment of fluid formation, upflow and outflow zones of a geothermal system at depth. Geochemical data from all wells indicate that the Sorik Marapi reservoir consists of dilute neutral Na-Cl brine (TDS ~1500-1900 mg/kg). The non-condensable gas (NCG) reservoir has low concentrations (up to 0.1% total weight NCG). In this study, the grouping of alteration zones is based on the quantity of alteration mineral assemblages. Therefore, the alteration zone at the research location is divided into 2, namely the Smectite - Hematite zone and the Illite - Epidote zone.

The Smectite-Hematite Zone is characterized by the emergence of smectite and hematite minerals in large quantities at shallow depths. In addition, there are also minor minerals such as magnetite, chlorite, pyrite and quartz with moderate to strong intensity levels. The smectite-hematite intensity category of this zone is classified as high, so it is interpreted as a clay cap zone. Judging from the presence of alteration minerals in this zone such as smectite as a key mineral and calcite, chlorite, quartz, and pyrite as accessory minerals, it is classified as an argillic alteration type (Guilbert, 1986). Based on geothermomers, this zone has a temperature ranging from 20 - 240 °C during its formation (Reyes, 2000).

The illite-epidote zone is characterized by the emergence of illite and epidote minerals in large quantities. In addition, there are also minor minerals such as pyrite, chlorite, quartz, and calcite at moderate to strong intensity levels, appearing in the form of veins. The illite-epidote intensity category of this zone is classified as high, so it is interpreted as a reservoir zone. Judging from the presence of alteration minerals such as illite, calcite, epidote and chlorite as key minerals, it is classified as a type of propylitic alteration (Guilbert, 1986). Based on the geothermometer, this zone has a temperature ranging from 240 - 330 ° C during its formation (Reyes, 2000). In this zone there is also a total loss circulation zone, with a high level of permeability which can be one of the characteristics of the reservoir zone.

- Well “TB-001” : the Smectite – Hematite mineral assemblage zone was identified at a subsurface elevation of 45 – 860 mMD (meter measured depth), and the Illite – Epidote zone was identified at a subsurface elevation of 860 – 2145 mMD.
- Well “TB-002” : Smectite – Hematite mineral assemblage zone was identified at subsurface elevation of 33 – 380 mMD and Illite – Epidote zone was identified at subsurface elevation of 380 – 1443 mMD.

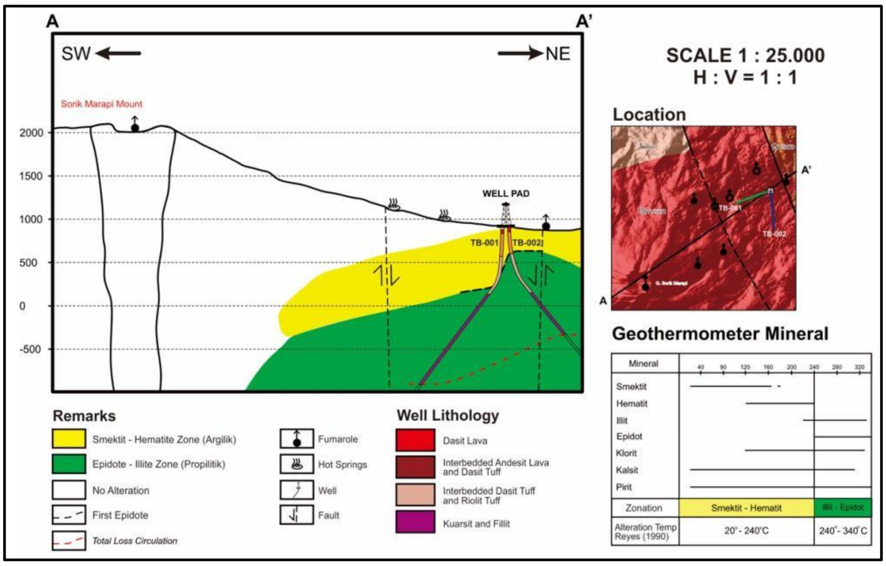

Figure 4. Alteration Zone Cross Section Reviewed From Well Data

3.2. Results of Well Water Chemical Content Analysis

To determine the characteristics of the type of fluid based on chemical content, we can use the Cl – SO_4 – HCO_3 triangle (Giggenbach, 1988). Figure 5 shows that the water samples from wells “TB-001” and “TB-002” have a higher amount of chloride (Cl) composition than sulfate (SO4) and bicarbonate (HCO3). These data illustrate that the fluid in wells “TB-001” and “TB-002” is a type of chloride water with a mature water category.

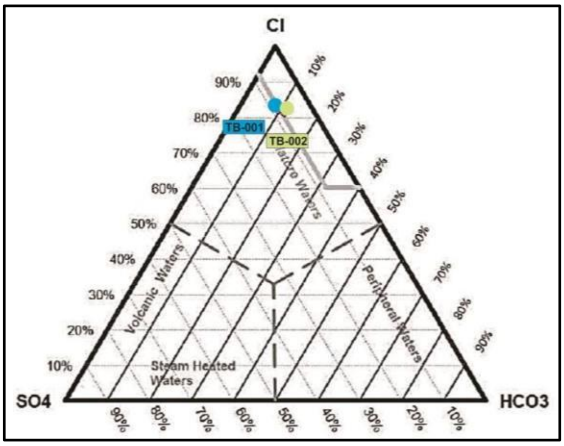

Figure 5. Fluid Type Analysis Using Cl – SO_4 – HCO_3 Triangle

In addition, the presence of dominant chloride (Cl) elements interprets that the well water samples analyzed came directly from the reservoir zone in addition to the minimum mixing with other fluids during the fluid migration process to the surface. It should be noted that in general the presence of chloride water is related to the presence of a high temperature geothermal system. Chloride water comes directly from the geothermal reservoir zone with quite high fluid circulation and shows the presence of a permeable zone (Hidayatullah, 2021). Meanwhile, there are surface geothermal manifestations of chloride water such as hot springs and geysers that have blue to green water colors as the main characteristics of chloride water. In terms of temperature, chloride water has a temperature of more than 200°C. In terms of subsurface conditions, below the surface it generally forms argillic to propylitic alteration types with the presence of characteristic minerals, namely albite, adularia, silica (amorphous silica, cristobalite, quartz), illite, chlorite, epidote, pyrrhotite, zeolite, calcite, and pyrite.

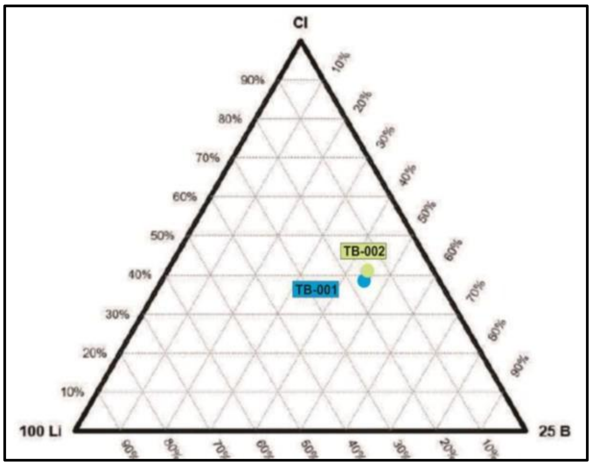

Figure 6. Fluid Source Analysis Using C1 – Li – B Triangle [5]

To find out the source of fluid based on chemical content, we can use the Cl – B – Li triangle (Giggenbach, 1988). Figure 6 shows that the well water samples "TB-001" and "TB-002" show a relatively high absorption ratio of the B/C1 elements. Then reviewed through the analysis, it can be interpreted that both samples come from the same reservoir zone.

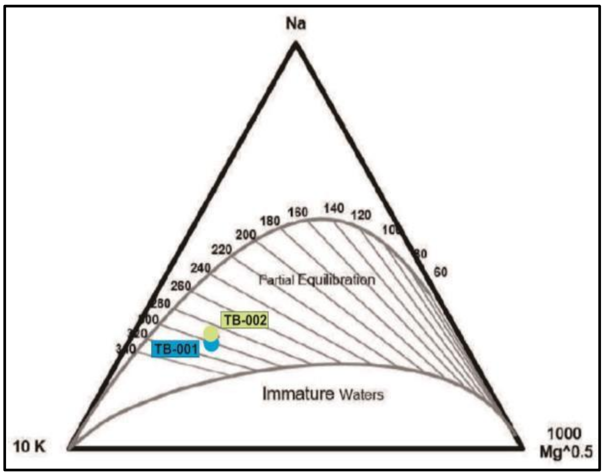

Figure 7. Fluid Temperature Analysis Using Na – K – Mg Triangle [5]

To determine the fluid temperature based on chemical content, the Na – K – Mg triangle can be used (Giggenbach, 1988). Figure 7 shows that the well water samples "TB-001" and "TB-002" are located in the partial equilibrium zone, meaning that the well water has gone through a partial mixing process with other fluids during the migration process. As is known, the type of fluid is chloride, so it is very suitable if used to determine the fluid temperature because chloride water comes directly from the reservoir. The water samples analyzed have temperatures ranging from 293 – 299 °C

3.3. Evaluation of Silica Scale Deposition Potential

The study and analysis of silica crust deposits were conducted on "TB-001" and "TB-002" wells of Sorik Marapi Geothermal Field. The analysis using geochemical water content data (chloride and silica) and temperature that had been converted through wellhead pressure and separator. Based on results of mathematical calculations on the "TB-001" and "TB-002" wells, it was found that there was no potential for silica crust deposits to form in the wellhead section of each well. This indicated by the results of t SSI value, which does not exceed one (<1) and classified as unsaturated. On the other hand, in separator section, the results of SSI value were obtained, which exceeded one (>1), classified as saturated/supersaturated, and had the potential for silica crust deposits. Silica will increase due to temperature and decrease due to salinity (Polimpung, 2021). Meanwhile, the composition of chemical compounds found and dissolved in water will increase because these compounds cannot be dissolved in vapor phase, so that an appropriate acidity (pH) setting is required so that the SSI value can be small (<1)

Table 1. Silica Saturation Index Analysis Results of Well "TB-001"

Well Part	Silica Concentration (ppm)	Pressure (barg)	Temp (C)	SSI	Velocity (inc/y)	Time (year)
Wellhead	810	16,45	215,20	0,770	No Potential	
Separator	884,710	7,12	173,835	1,137	2,80	1,71

Table 2. Silica Saturation Index Analysis Results of Well "TB-002"

Well Part	Silica Concentration (ppm)	Pressure (barg)	Temp (C)	SSI	Velocity (inc/y)	Time (year)
Wellhead	775	15,87	211,700	0,756	No Potential	
Separator	845,278	7,09	172,625	1,118	2,77	1,73

From the analysis and calculation, it was found that the wells "TB-001" and "TB-002" have the potential for the formation of silica crust deposits in the separator section, but not in the wellhead section. Reviewed from the analysis and calculation through the quartz and amorphous silica solubility indicators, the results of the silica crust formation rate were 2.80 inches/year in the well "TB-001" and 2.77 inches/year in the well "TB-002". Therefore, from the results of the formation rate, the pipe will be blocked up to 20% within 1.71 years in the well "TB-001" and 1.73 years in the well "TB-002". In an effort to minimize the formation of silica crust on production pipes, researchers recommend injecting a chemical solution of Hydrofluoride acid (HF), both in the well and production pipe. The chemical solution works by keeping the particles that form the silica crust in solution, so that it is expected that no precipitation will occur. This can happen because the solution works to prevent the formation of silica polymerization reactions caused by decreased silica solubility (Polimpung, 2021). The rate of silica polymerization will be minimal in acidic conditions and will increase with increasing pH. Some of the advantages of using HF in an effort to overcome the problem of silica crust on geothermal production pipes include HF having unique characteristics (very reactive with SiO2), being easily available on the market, and being economically priced. In addition, HF does not cause pollution after reacting with silica crust so that the possibility of affecting the geothermal reservoir is also small. However, acidification using HF has a negative impact, namely increasing the rate of corrosion on pipes and other components. Researchers will provide recommendations for HF concentrations and immersion times that are appropriate for the solubility of silica scale in HF solutions in an effort to overcome the problem of silica scale in production pipes, where the solubility data obtained will be combined with the corrosion rate so that the optimum concentration will be obtained in dissolving silica and having the lowest corrosion impact.

Table 3. SSI and PH Data Before HF Injection Concentration 15%

Well Separator	Pressure (barg)	Temp (C)	Silica (ppm)	pH Flash	pH Sep	SSI	Velocity (inc/y)	Life Time
TB-001	7,12	173,835	868,381	6,25	8,84	1,137	2,80	1,71 y
TB-002	7,09	172,625	845,278	6,40	8,60	1,118	2,77	1,73 y

Table 4. SSI and PH Data After HF Injection Concentration 15%

Well Separator	Pressure (barg)	Temp (C)	Silica (ppm)	pH Flash	pH Sep	SSI	Velocity (inc/y)	Life Time
TB-001	7,12	173,835	868,381	6,25	5	0,612	1,51	2,50 y
TB-002	7,09	172,625	845,278	6,40	5	0,588	1,46	2,55 y

Based on previous calculations, the estimated blockage time of TB-001 is faster than TB-002. This is due to the high salinity level and pH increase after flashing which results in an increase in the potential for silica crust formation and the rate of silica crust thickening. when the brine is treated with Hydrofluoric acid (HF), by changing the pH to 5, it is seen that the potential for silica crust is reduced (SSI <1). Thus, by maintaining the pH in the production pipe, the potential for silica crust formation can be avoided. In acidic conditions, the rate of polymerization of dissolved silica will be minimal. So that the reaction in forming silica is increasingly minimal and the production of the generator will be better

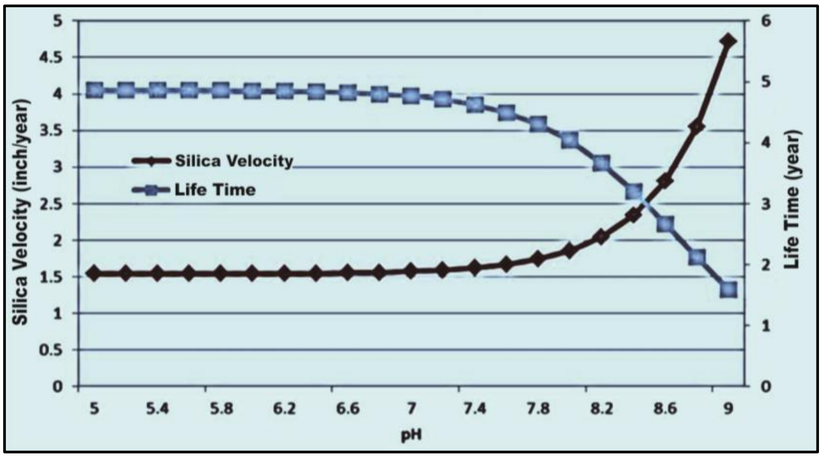

Figure 8. Silica Thickening Rate & Pipe Clogging Time Against pH Value

Researchers recommend that the most optimum HF concentration that can be used for mitigation is 15% because at that value it has the highest ability to dissolve silica crust until 21% and provides a life time 2.50 years for "TB-001" and 2.55 for "TB-002". The ability to dissolve HF in dissolving silica crust is maximized at a HF concentration 15% with an immersion time 15 minutes, which is 21% of crust weight. In terms of life time, this figure is still greater than silica crust blockage time so that the injection of HF at a concentration 15% can be an alternative to solve the problem of silica crust on the pipeline that occurs in the Sorik Marapi Geothermal Field. Corrosion was produced at the fastest rate at concentration 15%, which was 0.747 mm/y for TB-001 and 0.770 mm/y for TB-002. Corrosion rate continued to decrease with decreasing HF concentration. This shows a relationship that the higher the HF solution concentration, the higher corrosion rate experienced by the material on the production pipeline. Meanwhile, the effectiveness of HF acid injection ranges from 46 - 47%

IV. CONCLUSION

Alteration Zones occurring in the Sorik Marapi Geothermal Field consist of an Argillic zone with a set of smectite - hematite minerals formed at a temperature of 20° C - 240° C and a Propylitic zone with a set of Illite - Epidote minerals formed at a temperature of 240° C - 340° C. The characteristics of water in wells "TB-001" and "TB-002" are chloride water types produced from the same reservoir, with a reservoir temperature of 293° C - 299° C. The potential for silica crust deposits based on the SSI value of wells "TB-001" and "TB-002" at the wellhead obtained an SSI value <1 (undersaturated conditions) so that there is no potential for silica precipitation, while in the separator obtained an SSI value >1 (supersaturated conditions) which allows silica precipitation. Silica crust deposition that occurs in the separator results in a Silica formation rate of 2.89 inches/year in the “TB-001” well and 2.77 inches/year in the “TB-002” well. Based on the silica formation rate obtained, the pipe will be clogged up to 20% within 1 year 241 days in the “TB-001” well and 1 year 265 days in the “TB-002” well. To maintain the feasibility of the well and prevent the occurrence of silica crust deposits, researchers recommend injecting a Hydrofluoride (HF) acid solution with a concentration of 15% and an immersion time of 15 minutes when mitigating silica crust, which will increase the well life time to 2.50 years for “TB-001” and 2.55 years for “TB-002”. The effectiveness of HF acid injection in preventing the formation of silica crust ranges from 46 - 47%.

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