Characteristic of Geothermal System at Semurup Manifestation, Kerinci: Geological and Geochemistry Investigation-Based

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Abstract. Semurup Village on Kerinci Regency, Jambi is indicated potential for geothermal resources; it is proved by the presence of hot springs (Gao Luluk, Gao Dili, and Gao Mudik), non-active geyser, and silica sinter deposit. This research aimed to investigate reservoir characteristics which the approach was to interpret the Semurup hot spring fluid type and reservoir temperature based on elements fluid contained. This research was carried by the analysis of B, Al, Ca, Mg, Na, K, Li, F, Cl, SO4, HCO3 contained of hot spring for reservoir characterization conducted by Cl-SO4-HCO3, B-Li-Cl, and Na-K-Mg ternary diagram and conductive silica geothermometer for reservoir temperature estimation. Semurup hot spring was classified by volcano-tectonic geothermal system, because it was associated with Quartenary Lumut Volcano and Sumatran Fault Zone. Unit stratigraphy was composed by Eocene pyroclastic rocks of Bandan Formation (kaoliniteclay minerals, calcite, feldspar) and Undifferentiated Volcanic Rock Formation (silica minerals, chlorite, and calcite). Geological setting was possibly vary of hot springs (chloride - bicarbonate) and deposits (silica - bicarbonate). There were three types of geothermal manifestation, which were neutral hot spring, geyser, and silica sinter. The result showed that GaoLuluk fluid was dominated by Cl at 53.06% while that of GaoMudik was high in bicarbonate at 72.81%. Silica conductive geothermometers gave equilibrium reservoir temperatures ranging from 166°C - 241°C. Based on the geological and geochemical investigation, the reservoir fluid of Semurup manifestation had occured dilution with calcite-contained on groundwater and the reservoir temperature was classified as moderate - high, which was high potential for geothermal energy resource.

1. Introduction
Over the 20th century, with the significantly rapid development of human society, energy has become an extremely vital issue. As a source of clean and sustainable energy, geothermal power has attracted increase attention. Development of geothermal energy in over 20 countries around the world has become more widespread such USA, Iceland, Italy, Germany, Turkey, Indonesia, France and Netherlands (e.g. Guo and Wang, 2012). Indonesia is high potential for geothermal resource, because 40 % world
geothermal resource are located in Indonesia (Bertani, 2015). Geothermal system in Indonesia are associated with Quaternary volcanism (Sumatra, Java, Bali, Nusa Tenggara, Banda Islands, and North Sulawesi) and non volcanic environment (Kalimantan, most of Sulawesi, Buru Islands, and Papua) (Center for Geological Resources, 2013). In Sumatra island, Kerinci regency is one of the prospect area where the geothermal system is indicated with the occurrence surface geothermal manifestation, such as hotspring, non-active geyser, and silica sinter. These surface geothermal manifestations were found in Semurup Village, Kerinci (Fig 1).

One of the main steps in the exploration of geothermal resources is to estimate subsurface/reservoir temperature and intreprete fluid hotspring characteristic which correlate with reservoir fluid. The most commonly used for estimating reservoir temperature are silica geothermometers, Na-K and Na-K-Mg relationship (Fournier, 1993; Fournier and Truesdell, 1973; Ellis and Mahon, 1997; D’Amore and Arnorsson, 2000), and characterizing hot spring fluid interpretation using Cl – SO₄–HCO₃ ternary diagram (Giggenbach, 1991).

Therefore, the goal of this study is to examine the fluid characteristics and estimate the reservoir temperature at depth of selected hot spring manifestation in order to assess their potential as an indirect utilization, especially for alternative source of renewable energy or direct utilization, such tourism. The most important point is the Information and data from this research can be used as guidance for geothermal companies and involved agencies for detailed exploration.

2. Geology Settings Of Kerinci Geothermal Manifestation
Kerinci and surrounding is part area of traversed of Sumatran Fault Zone, Natawidjaja (2017), Sieh and Natawidjaja (2000), Muraoka (2010). It is associated of volcanic system, (Muraoka, 2010) and Kasbani (2009). Hochstein and Sudarman (2008) the existence of geothermal manifestation on the Semurup hot spring associated to Sumatran Fault Zone and Lumut Volcano (Fig 1). Thus thermal manifestation is indicated of geothermal volcano-tectonic system.

![Figure 1. Some geothermal prospects in Sumatra explored of 1970 – 2000, hence characteristic of high temperature geothermal system the associated of Quartenary volcanic product, in Hochstein and Sudarman (2008). Numbre 54 is located area](image)

3. Samples And Methods
Two water samples were collected from the different hot spring. Sample code AP-1A represent Gao Luluk hot spring, and AP – 2A represent Gao Mudik (Fig 2 and Fig 3). Before sampling the water, every surface manifestation were observed through their physical characteristic such as; water temperature,
potensial of hydrogen (Ph), water colour, carbonate test for sinter silica. These characteristics described in Table 2. Water samples were filtered through 0.45 µm membranes on site and stored in 1.5 L polyethylene jars which had been rinsed with deionized water twice prior to sampling. The both of water sample were analyzed for B (Boron), Al$^{3+}$ (Alumunium), Fe (Besi), Ca$^{2+}$ (Calsium), Mg$^{2+}$ (Magnesium), Na$^+$ (Natrium), K$^+$ (Kalium), Li$^+$ (Lithium), F$^-$ (Fluor), Cl$^-$ (Klorida), SO$_4^{2-}$ (Sulfat), HCO$_3$ (Bicarbonat), SiO$_2$ (Silica) at Laboratories Pusat Sumber Daya Mineral Batubara dan Panas Bumi, Bandung, Indonesia. Ca, Mg, K, Fe, and SO$_4^{2-}$ were analyzed by inductively coupled plasma (ICP), while SiO$_2$, Cl, and F were analyzed using UV spectrophotometer, and HCO$_3$ was analyzed by titration method. Result analysis of the elements are summarized in Table 1. Ion balance calculation are also performed to assess the eligibility samples. Ion balance calculation is following this equation: $\frac{\sum \text{anions} - \sum \text{cations}}{\left(\sum \text{anions} + \sum \text{cations}\right)}$, and the result should not be greater than 5%. After the analyzing the hot spring water, the data was processed through chemistry analysis which resulted in the form of plotting in the Giggenbach Cl – SO$_4$ – HCO$_3$ ternary diagram to find out and interpret characteristic of water in Semurup area. The estimated reservoir temperatur / subsurface temperature were done by using SiO$_2$ conductive silica geothermal formula.

**Figure 2.** The Surface of geothermal manifestation at Semurup area; (A) Gao Luluk hot spring, (B) Gao Dili hot spring, (C) Gao Mudik hot spring, (D) Silica Sinter; precipitation product of geothermal fluid.

**Figure 3.** The Surface of geothermal manifestation at Semurup area; The Comparison conditions of the geyser dome before experiencing water depletion (A) (Hochstein and Browne, 2000) with current
4. Result

Before sampling, the focus of analyzing was only on the hot spring of Gao Luluk and Gao Mudik, because they represented 2 different locations. Chemical analysis was carried out to determine the composition and value of the chemical constituents contained in geothermal manifestations.

4.1 Fluid Type Interpretation (Cl-HCO$_3$-SO$_4$)

Data required for interpreting the hot spring fluid type are relative content of chloride (Cl), bicarbonate (HCO$_3$), and sulphate (SO$_4$). Data processing was carried out by calculating the percentage of Cl, HCO$_3$, and SO$_4$ (Table 2) and plotting the data into Giggenbach ternary diagram (Fig 4). This diagram interprets the hot spring reservoir characteristics such as mature waters, peripheral waters, and volcanic waters.

**Table 1. Percentage of element content Cl - SO$_4$ - HCO$_3$**

| No | Location | No sample | Cl (ppm) | SO$_4$ (ppm) | HCO$_3$ (ppm) | Total (Cl + SO$_4$ + HCO$_3$) | %Cl | %SO$_4$ | %HCO$_3$ |
|----|-----------|-----------|----------|-------------|----------------|-----------------------------|-----|--------|--------|
| 1. | GaoLuluk  | AP-1B     | 460,49   | 150,49      | 257,04         | 868,02                      | 53,06 | 17,33  | 29,61  |
| 2. | GaoMudik  | AP-2A     | 217,9    | 43,6        | 700,41         | 961,91                      | 22,65 | 4,53   | 72,81  |

The value obtained for the Cl, HCO$_3$, and SO$_4$ content indicated an anomaly from both hot springs despite of the short distance among them, at merely 1 km. Based on the result of Giggenbach ternary diagram interpretation, the hot spring manifestation in Semurup Area AP-1B was classified as chloride-bicarbonate and AP-2A bicarbonate water.

4.2 Fluid Type Interpretation (Na-K-Mg)

Based on Na-K-Mg ternary diagram (Fig 5), GaoLuluk and Gao Mudik hot springs were located at partially equilibrium zone, where the fluids undergo partial chemical equilibrium. At this zone, the chemical composition of fluid that flows from reservoir to the surface would change but still not...
sufficiently strong to be located at fully equilibrium zone. This zone interprets that the fluids undergo mixing and dilution (Giggenbach, 1988).

The Na-K-Mg diagram was also used to estimate the reservoir temperature. The diagram shows that the reservoir temperature in Gao Luluk hot spring ranges from 120 – 220°C which could be classified as high temperature geothermal system (SNI 13-6482-220).

### Table 2. Location and characteristics of Surface Manifestation in Semurup area.

| No. | Location                  | Observation Date | No. Sample | Coordinate | T(°C) water | T ambient | pH  | Manif. type | Description                                                                 |
|-----|---------------------------|------------------|------------|------------|-------------|-----------|-----|-------------|-----------------------------------------------------------------------------|
| 1   | Semurup hot spring 1. Goa Dili (AP1A), Gao Luluk (AP-1B) | 20 July 2018    | AP-1A      | 101°21'434"N 01°59'292"E | 84°C 80.5°C 84.7°C | 30.6°C 30.9°C 29.8°C | 7.4 | Hot Spring | Clear, has residual silica around the spring. Some spots are identified redish deposit (oxidation), odorless sulfur. |
| 2   | Semurup hot spring 2. Gao Mudik (AP-2A)                | 20 July 2018    | AP-2A      | 101°21'474"N 01°59'289"E | 94.6°C 94.7°C 94.7°C | 26.8°C 26.9°C 27.2°C | 7.2 | Hot Spring | Clear, has residual silica around the spring. Some spots are identified redish deposit (oxidation), Odorless Sulfur. |
| 3   | Geyser dome               | No sampling     | SS-1       | 101°21'410"N 01°59'280"E | 75°C 77.3°C 82.8°C | 28.6°C 28.6°C 29.2°C | 7.6 | Hot Spring | Clear, has residual silica around the geyser, experiencing water shrinkage. |
| 4   | Rock of hot spring 1      | 20 July 2018    | SS-1       | 101°21'444"N 01°59'291"E |         |            |     | Silica sinter | Colour white, brittle, interpreted as product of hydrothermal precipitation. |
| 5   | Rock of hot spring 2      | 20 July 2018    | SS-2       | 101°21'297"N 01°59'164"E |         |            |     | Silica sinter | Colour white, brittle, interpreted as product of hydrothermal precipitation. |

*Note: T amb = T ambient*
Fig 5. Diagram Ternary Giggenbach element content Na-K-Mg of Gao Luluk hot spring (AP-1A) and Gao Mudik (AP–2A).

4.3 Temperature Estimation based on Conductive Silica Geothermometer

Conductive silica geothermometer indicates that the temperature of geothermal reservoir ranges from 166°C to 241°C, as shown in Table 4. Based on SNI 13-6842-220, the geothermal reservoir in Semurup area had enormous potential for geothermal steam power plant because the temperature range was classified as moderate to high (Table 4).

Conductive silica geothermometer

\[ T^\circ C = \frac{1309}{5.19 - \log \text{SiO}_2} - 273 \]  

(Fournier, 1997)

Table 3. Calculation of conductive silica geothermometry

| No | Location  | SiO2 (ppm) | Log SiO2 | 5.75 – Log SiO2 | 1309/5.19-Log SiO2 | (1309/5.19 – Log SiO2)-273 |
|----|-----------|------------|----------|-----------------|-------------------|---------------------------|
| 1  | AP-1B GaoLuluk | 440.13 2.64358097 | 2.546419028 | 514.05 | 241 |
| 2  | AP-2A GaoMudik | 162.7 2.21138755 | 2.978612447 | 439.466 | 166 |

Table 5. Estimation of geothermal reservoir temperature based on SNI13-6482-2000

| No | Location  | T°C | Classification based on SNI 13-6482-2000 |
|----|-----------|-----|----------------------------------------|
| 1  | AP-1B GaoLuluk | 241 | High temperature geothermal system |
| 2  | AP-2A GaoMudik | 166 | Moderate temperature geothermal system |

4.4 Observation Mineral Composition of Silica Sinter Rock.

Rock surrounding the hotspring was classified as silica sinter deposit. Silica sinter was identified at both of hot springs location; location 1 (Gao Luluk and Gao Dili) and location 2 (Gao Mudik). From petrography result on 2 samples (SS-1 and SS-2), it was identified some non opaque mineral; such as: quarza with high domination, smectite, kaolinite, and chlorite.
5. Discussion

Geothermal manifestation on Semurup hot spring is appeare on volanic product of Lumut Volcano (Fig 7). Alteration rock with silicified type-silica sinter is characteristic of the existence Semurup hot spring. Petrographic was analyzed to shown hydrothermal alteration silica sinter with consisting of dominantly secondary quartz, amorphous silica, mixed of clay alteration (kaolinite-smectite), and chlorite (see Fig 6). Quartz and amorphous silica was indicated of mineral formed directly hydrothermal fluid processes upwelling and crystallization to pathway/fracture, whereas amorphous silica was effected of multiphase hydrothermal fluid system on feldspar minerals. Clay minerals was response of minerals to hydrotermal alteration and generally associated to silicified/silica sinter zonation. Chlorite is commonly minerals hydrothermal system and abundant on propylitic zone as reservoar rock on geothermal system. Mineral composition was indicated of geothermal system with assoiciated volcanic system.

Geological setting is possibly vary of hot springs and deposits hydrothermal contain. Difference type of hot spring were found; Gao Luluk hot spring (AP-1B) which Cl was high, whereas on Gao Mudik hot spring (AP-2A) which HCO3 was high. Variety of water condition was not comparable to hydrothermal deposits, because hydrothermal deposits are silica sinter type deposit (see Figure 6). The fact that on Gao Mudik hot spring contain was high amount of HCO3, thus the interpreted sinter silica have formed of paleo hydrothermal fluid which SiO2 was high and Cl containing. The high of HCO3 depended on the effect of mixing hydrothermal fluid to wall rock of Eosene pyroclastic rocks of Bandan Formation (kaolinite clay minerals, calcite, feldspar) and Undifferentiated Volcanic Rock Formation (silica minerals, chlorite, and calcite).

Sumatran Fault Zone was formed fault segment, consist of 19 segmented, fault Siulak segment, Sieh and Natawidjaja (2000). Siulak segment had north-northwestern - south-southeastern orientation (see Fig 7). Siulak segment had conducted tectonic Sumatra with control of extention stress. There had horst grabben system of Kerinci valley formed. Thus, it had been trigerring upwelling the outflow spring manifestation Semurup on pathway (grabben-fault system). Hence, spring thermal manifestation was not only volcanic system, but also tectonic geothermal system.
Based on Cl- SO₄-HCO₃ ternary diagram plotting, hot springs type in Semurup area were classified as Chloride – Bicarbonate water, and bicarbonate water. The type of geothermal water identified in the hot spring Gao Luluk was type of chloride by mixing elements of bicarbonate, otherwise known as water chloride – bicarbonate, this was indicated by dominant chloride value of 490,49 ppm, but also the mixing of bicarbonate elements which was relatively very high, which was equal 257,04 ppm. Type of bicarbonate water generally had clear water and did not smell pungent. Types of chloride diluted with bicarbonate elements generally have Ph 6 – 8 (Nicholson, 1998). This was accordance with the measurement of the physical characteristics of manifestations in the field, the pH of the water in the Goa Luluk spring was 7.2. The type of chloride water was indicated as geothermal fluid originating from the geothermal reservoir, and could reach concentrations reaching 10,000 mg / kg (Nicholson, 1993). The type of water chloride was clear and contained little iron, and generally there could be sintered silica, which was a product of silica precipitation in geothermal fluid discharge areas (Fournier and Rowe, 1996; Weres and Apps, 1982; Fournier, 1985; Williams and Crear, 1985). In Semurup area, the hot springs of Gao Luluk and Gao Mudik was identified terrace-shaped sintered deposits around hot spring discharges.

Whereas in hot spring manifestation Gao Mudik was classified as a type of bicarbonate water. The bicarbonate element which was dominant in geothermal fluid was due to the process of condensing CO₂ gas with ground water (peripheral zone). The relatively high composition of HCO₃ generally came from mixing with surface water. According to Nicholson, 1993, HCO₃ was formed from the reaction of condensation of CO₂. Parameters that played a role in the formation of the HCO₃ concentration was from the partial pressure on the carbon dioxide element in the fluid that was relatively deep and also the pH solution parameter. The loss of carbon dioxide in boiling activity would increase the Ph solution ...
(close to neutral) (Nicholson, 1993). In measuring the physical characteristics of the manifestations, it was found that the bicarbonate springs in the hot springs of Gao Mudik had a neutral pH of 7.6, higher than the pH of Gao Luluk. The type of bicarbonate water generally produced precipitation in the form of travertine rock, but it did not rule out the possibility of forming sintered silica. In the study of rocks, the results of precipitation of geothermal fluid were silica sintered rocks. The high presence of bicarbonate (HCO3) elements could also be associated with geothermal systems. The higher the concentration of HCO3 interprets the manifestation system that is far from the uplow zone and the closer it is to the outflow zone (Aribowo, 2015).

The use of the Na-K-Mg triangle diagram in principle was to interpret the characteristics of water throughout its journey from the reservoir to the surface, where this process was affected by dissolution of the solution and equilibrium. The process of dissolving rocks, besides causing the elements in the fluid to change. The occurrence of fluid interactions with rocks would produce new fluid characteristics. In the diagram, Gao Luluk’s hot springs and Gao Mudik’s hot springs were in a partially equilibrium zone, where the fluid experienced a partial chemical equilibrium, where as long as the fluid moved from the reservoir to the surface, new chemical composition changed although the intensity is not zone with fully equilibrium. In partially equilibrium zones interpret that fluid experiences mixing and dilution (Giggenbach, 1988). In the triangle diagram (Figure), there was a mixture of Cl elements indicating the reservoir fluid against the HCO3 element which indicated groundwater activity.

6. Conclusion
Based on the data analysis, there are several points that can be concluded. Firstly, the dominant proportion of chloride (Cl) at 469 ppm and bicarbonate (HCO3) at 700.41 ppm obtained from the Giggenbach ternary diagram shows that Gao Luluk and Gao Mudik hot spring manifestations were classified as chloride-bicarbonate and bicarbonate water respectively. Secondly, the high Cl concentration indicates that the fluid was sourced from permeable zone of reservoir while the bicarbonate was sourced from the condensation of reservoir with surface water. Lastly, the GaoMudik and Gao Luluk reservoir temperature estimated based on ternary diagram are 120°C and 220°C respectively while that estimated based on conductive silica geothermometer ranges from 157 – 241°C. This temperature range was classified as moderate to high therefore Semurup manifestation has enormous potential for geothermal steam power plant.

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