Geochemistry of warm springs in the *Ie Brôuk* hydrothermal areas at *Aceh Besar* district

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Abstract. Indonesia is a country with the largest geothermal potential resource in the world, estimated of 28,617 MW or equivalent to 40% of the world's geothermal potential. Geothermal energy is environmentally friendly and quite economical compared to fossil energy. *Seulawah Agam* is one of Indonesia's geothermal fields that has several manifestation zones, including *Ie Brôuk* (BH1 and BH2) manifestations. The analysis for this study was conducted by acid-base titration, UV-Vis Spectrophotometry and Atomic Absorption Spectroscopy (AAS). The data analysis of cations and anions were plotted in liquid chemistry worksheet plotting spreadsheet version 3 Powell geoscience September 2012 by Powell and Cumming. The type of manifestation fluid is bicarbonate, obtained from the geoindicator Cl-SO4-HCO3, while the water condition is immature based on Na-K-Mg ternary diagram. The *Ie Brôuk* reservoir temperature was 289 °C and 291 °C obtained from Na/K geothermometer Tonani (1980) and Na/K Gigenbach (1988) respectively. Therefore, the *Ie Brôuk* manifestation classified as a high-temperature geothermal system.

1. Introduction
Indonesia's geothermal energy potential reaches 28,617 megawatts (MW) [1] or about 40% of the total geothermal energy potential in the world [2] scattered in several regions in Indonesia such as Sumatra, Java, and parts of eastern Indonesia [3]. Geothermal energy is environmentally friendly and economical enough [4] when compared to fossil fuels. Indonesia has started the exploration of geothermal energy since 1970 [5]. Aceh is one of the provinces that has some active volcanoes, i.e *Jaboi, Seulawah Agam, Geuredong*, and *Burni Telong* which suggest to have the potential of geothermal energy [6], one of which is Mount *Seulawah Agam* located in *Aceh Besar* district [7].

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Seu'um manifestation around Seulawah Agam Mountain is one manifestation of which the geothermal exploration has been carried out, where the reservoir temperature is 188.7±9.3 °C and the water type is chloride [8]. In this study, the determination of Ie Brôuk (BH1 and BH2) characteristic was determined using geoindicator equation of Cl-SO₄-HCO₃ and ternary diagram of Na-K-Mg, while the temperature interval of Ie Brôuk reservoir measured using the equation of Geothermometer Na/K [9, 10, 11, 12, 13, 14] and Geothermometer Na/K/Ca [15].

2. Methods and Materials

2.1 Site Sampling and Field Data Measurement

Ie Brôuk geothermal manifestations are located in the village of Lam Apeng, Lamteuba, Seulimum sub-district, Aceh Besar, that is in the up-flow zone of Seulawah Agam. The characteristics of Ie Brôuk manifestations were shown by the slightly turbid water color, the warmth, the amount of air bubbles and small debit. The manifestations were surrounded by bushes, mossy rocks, leeches and many trees. The maps of sampling location was observed through satellite image (google earth), geological map, temperature map, and lineament density map in figures 1, 2, 3 and 4 respectively. Before the water sample was taken, the warm spring surrounding area was cleaned up. Initial measurements were carried out which included sampling point coordinates, elevation, temperature, pH, conductivity and total dissolved solids (TDS) of surface water. The geothermal surface water samples were filtrated using Whatman filter paper with a 0.45μm pore size, then the filtrate was put into the polyethylene (PE) bottle and acidified by adding 3N HNO₃ solution for pH adjustment for cations measurements, while for anions measurement, the filtrate was not acidified.

2.2 Materials and Instruments

The materials used in this study were Whatman filter paper with a pore size of 0.45 μm, demineralized water, NaCl solution, HNO₃ solution, HCl solution, AgNO₃ solution, orange methyl indicator, phenolphthalein indicator, potassium chromate indicator, sulfaver powder, potassium standard solution (1000 mg/L), sodium (1000 mg/L), calcium (1000 mg/L) and magnesium (1000 mg/L). Instruments used in this study included Portable pH meter, TDS meter, Conductometer (Schott Instrument), Portable Temperature (Fisher Scientific Traceable), Atomic Absorption Spectroscopy (AAS) (Shimadzu 6200), UV-Vis Spectrophotometer (DR/2010), GPS (Garmin 62S), analytical balance, polyethylene bottles, universal pH indicator, gloves, plastic bucket, titration apparatus, spatulas, hot plate and cooler boxes.

2.3 Measurements and Data Processing

Analysis of anion content of bicarbonate (HCO₃⁻), Chloride (Cl⁻) and sulphate (SO₄²⁻) was respectively carried out by acidimetry, argentometry (mohr) and UV-Vis spectrophotometry methods. Analysis of the cation content of Potassium (K⁺), Magnesium (Mg²⁺), calcium (Ca²⁺) and sodium (Na⁺) of warm water samples were measured using Atomic Absorption Spectroscopy (AAS). The uncertainty determination of cations concentrations is based on \( S_y \) equation (standard deviation of concentration). The Standard deviation in concentration can be found from the standard error of the estimate, also called as the standard deviation of the regression [16].

The data content of cations and anions then were plotted in liquid chemistry worksheet plotting spreadsheet version 3 Powell geoscience September 2012 by Powell and Cumming [17]. The output of the geothermal fluid type and geothermal fluid chemical equilibrium were exhibited in Cl-SO₄-HCO₃ and Na-K-Mg ternary diagram respectively. The depth temperature estimate was calculated using geothermometer Na-K and Na-K-Ca equations from several references which can be seen in table 1.
3. Result and Discussion

3.1. Location and Surface Characteristics of Ie Brôuk Manifestation
Measurements of surface water characteristics and warm water sampling were conducted on November 20th, 2017 at two sampling locations BH1 and BH2. The measurements were carried out on-site with five repetitions and the uncertainty measurement can be seen in table 2.

Table 1. Temperature equations (°C) for geothermometers

| Geothermometer | Equations |
|----------------|-----------|
| Na – K Truesdell (1976) [13] | \( T = \frac{855.6}{0.857 + \log(\text{Na/K})} - 273.15 \) |
| Na – K Tonani (1980) [14] | \( T = \frac{833}{0.780 + \log(\text{Na/K})} - 273.15 \) |
| Na – K Arnorsson (1983) [11] | \( T = \frac{1319}{1.699 + \log(\text{Na/K})} - 273.15 \) |
| Na – K Fournier (1979) [9] | \( T = \frac{1217}{1.483 + \log(\text{Na/K})} - 273.15 \) |
| Na – K Nieva & Nieva (1987) [12] | \( T = \frac{1178}{1.470 + \log(\text{Na/K})} - 273.15 \) |
| Na – K Giggenbach (1988) [10] | \( T = \frac{1390}{1.750 + \log(\text{Na/K})} - 273.15 \) |
| Na-K-Ca Fournier and Truesdell (1973) [15] | \( T = \frac{\log \left( \frac{Na}{K} \right)}{1647} + \beta \left[ \log \left( \frac{Ca}{Na} \right) \right] + 2,06 - 273 \) for: \( \beta = 4/3, \text{ if } T < 100^\circ \text{C} \) \( \beta = 1/3, \text{ if } T > 100^\circ \text{C} \)
The 8th Annual International Conference (AIC) 2018 on Science and Engineering  
IOP Conf. Series: Materials Science and Engineering 523 (2019) 012010  doi:10.1088/1757-899X/523/1/012010

### Table 2. *Ie Brów* manifestation surface characteristics

| Sampling Points | Coordinate | Elevations (m) | T<sub>water</sub>±Sd (°C) | pH±Sd | Conductivity ±Sd (mV) | TDS±Sd (mg/L) |
|-----------------|------------|----------------|----------------|--------|-----------------------|---------------|
| BH1             | 5º 31.077  | 95º 37.034     | 210             | 40.2 ±0.05 | 7.13±0.03               | 602.4±1.14    | 298.4±1.14    |
| BH2             | 5º 31.048  | 95º 36.948     | 197             | 49.5 ±0.09 | 7.04±0.03               | 553.2±0.84    | 125.64±0.93   |

The temperature at sampling point BH2 (49.5±0.09 °C) is higher than BH1 (40.2±0.05 °C). *Ie Brów* manifestation has neutral pH and conductivity along with TDS is relatively high due to organic material dissolved in sedimentary rocks around the manifestation [19]. The sample of warm waters from BH1 and BH2 were analyzed in the laboratory to determine the anion and cation contents.

#### 3.2. The Fluid Type of *Ie Brów* Manifestation

The fluid type (sulphate, bicarbonate or chloride types) of *Ie Brów* manifestation (BH1 and BH2) were determined based on the dominant value of the anion content that can be seen in Table 3.

### Table 3. The concentration of the Bicarbonate, Sulphate and Chloride anions of warm spring samples at *Ie Brów* Manifestation

| Sampling Points | HCO<sub>3</sub>±Sd (mg/L) | SO₄²⁻±Sd (mg/L) | Cl⁻±Sd (mg/L) |
|-----------------|--------------------------|----------------|--------------|
| BH1             | 292.6±0.26               | 33.87±0.85     | 12.98±0.01   |
| BH2             | 284.03±0.03              | 12.15±0.01     | 21.19±0.04   |

*Ie Brów* manifestation has a higher content of bicarbonate anion compared to sulphate and chloride. The anion data was used to plot Cl–SO₄–HCO₃ ternary diagram on determining the fluid type of manifestation. Based on figure 5, BH1 and BH2 are indicated as bicarbonate fluid type. This observation signifies the effect of high CO₂ content from the gas or steam condensation process at geothermal springs [19].

#### 3.3. Ternary Diagram Na–K–Mg

The Na-K-Mg ternary diagram is used to explain geothermal fluids at equilibrium in lithology based on cation content. The results of the laboratory measurement of the calcium, sodium, potassium and magnesium cation content for each sampling point are described in table 4.

### Table 4. The concentration of the Potassium, Sodium, Calcium and Magnesium cations of warm spring samples at *Ie Brów* manifestation

| Sampling Point | K⁺±Sc (mg/L) | Na⁺±Sc (mg/L) | Ca²⁺±Sc (mg/L) | Mg²⁺±Sc (mg/L) |
|----------------|--------------|---------------|----------------|---------------|
| BH1            | 18.87±0.20   | 116.30±0.23   | 3.60±0.16      | 32.75±0.01    |
| BH2            | 19.61±0.20   | 101.62±0.23   | 4.23±0.18      | 60.38±0.01    |

The cation data were plotted on the ternary diagram of Na-K-Mg to identify the condition of water, whether or not it has reached the equilibrium in lithology. The warm spring samples of *Ie Brów* manifestation (BH1 and BH2) indicated as immature water (figure 6). This condition showed that the concentration of dissolved cations in geothermal water had been mixed with the surface water, so it has not reached chemical equilibrium yet [18]. Cation data is also used to estimate reservoir depth temperatures based on geothermometer equations.
3.4. Determination of Reservoir Temperature at *Ie Brôuk* Geothermal Manifestations

Geothermometer is an equation that is used to estimate the temperature of the subsurface (reservoir). Chemical equilibrium temperature is highly influenced by cation concentration that is used as temperature control of the reservoir [19]. The result of the calculation from several geothermometers on *Ie Brôuk* geothermal manifestation can be observed in Table 5.

**Table 5.** Depth temperature calculation using several geothermometers for *Ie Brôuk* geothermal manifestations

| Sampling Points | Na-K-Ca Fournier and Truesdell [15] | Na/K Fournier [9] | Na/K Truesdell [13] | Na/K Giggenbach [10] | Na/K Tonani [14] | Na/K Nieva & Nieva [12] | Na/K Arnorsson [11] |
|-----------------|-------------------------------------|------------------|---------------------|---------------------|------------------|------------------------|---------------------|
| BH1             | 181 °C                              | 262 °C           | 246 °C              | 274 °C              | 289 °C           | 248 °C                 | 250 °C              |
| BH2             | 175 °C                              | 281 °C           | 271 °C              | 291 °C              | 318 °C           | 266 °C                 | 273 °C              |

The estimation of the reservoir depth temperature of the *Ie Brôuk* manifestation BH1 is 289 °C (Na/K Tonani, 1980) and BH2 is 291 °C (Na/K Giggenbach, 1988) (Table 5). The depth temperature is classified into three geothermal systems: low temperature (<125 °C), medium temperature (125-225 °C) and high temperature (>225 °C) [18]. Based on this classification, the manifestation of *Ie Brôuk* is the high temperatures geothermal system. According to calculated equations on the depth temperature estimation, all geothermometers Na/K delivered the same result in an average of 180 to 300 °C and the depth temperature is good if the result is close to 300 °C [19]. In this study, only the geothermometer Na/K Tonani (1980) and Na/K Giggenbach (1988) showed the good result.

4. Conclusion

The geothermal fluid of *Ie Brôuk* manifestation is bicarbonate water type based on a Cl-SO\textsubscript{4}-HCO\textsubscript{3} ternary diagram with neutral pH. The manifestation of *Ie Brôuk* based on the Na-K-Mg ternary diagram indicates the manifestation to be immature water. This condition showed that the concentration of dissolved cations in geothermal water had been mixed with surface water, so it has not reached chemical equilibrium yet. In this study, the estimation of the reservoir depth temperature of the *Ie Brôuk* manifestation BH1 is 289 °C (Na/K Tonani, 1980) and BH2 is 291 °C (Na/K Giggenbach, 1988). The results of this calculation explained that the manifestation of *Ie Brôuk* is classified as a high temperature geothermal system.
5. References

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