Geochemistry of Sulphate spring in the Ie Jue geothermal areas at Aceh Besar district, Indonesia

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Abstract. Geochemical studies of geothermal manifestations in the Northern Zone of Mt. Seulawah Agam, one of which is Ie Jue manifestation, has been conducted. In this study, water geochemical analysis of cations and anions content was performed to observe the surface characteristics of manifestations, the type of water manifestation, the water balance of reservoir depth and to estimate depth temperature using geothermometer equations. Cations and anions measurements were conducted using atomic absorption spectroscopy, UV-Vis spectrophotometer and acid-base titration. The data analysis was determined using spreadsheet version 3 Powell Geoscience Ltd.3 September 2012 by Powell & Cumming. The geothermal water Ie Jue manifestation was acidic pH, water sulphate type was obtained from the geoindicator Cl−SO4−HCO3 and the immature water was based on plot Na-K-Mg ternary diagram. Its reservoir temperatures ranged from 690 ºC to 761 ºC in accordance with Na/K geothermometer equations based on results of Na/K Giggenbach and Fournier. The Ie Jue manifestations indicated a high-temperature geothermal system (high enthalpy) that could be characterized when the average temperature reached higher than 225 ºC and suitable for power plant development.

1. Introduction
Indonesia is located in the area of "The Ring of Fire", which is a belt that has the most volcano up to more than 200 volcanoes, where 129 active volcanoes spread over from Sumatra, Java, Sulawesi to eastern parts of Indonesia [1]. There is a high amount of geothermal energy potential, so that research
on the potential or prospect of geothermal in various regions of Indonesia is important in order to obtain a qualitative and quantitative picture of the geothermal energy potential [2]. Potential geothermal resources in Indonesia have been exploited such as Kamojang, Darajat, Salak Mountain, Dieng, Sibayak, Wayang Windu, Lahendong, Ulu Belu, Mataloko and Ulumbu [3]. Therefore, it is also necessary to explore and exploit other geothermal resources especially in Aceh province.

Aceh province is one of the areas in Sumatra that has geothermal energy potential, especially Mount Seulawah Agam. Based on the previous exploration, there are found many locations of manifestations such as Ie Seu’um, Ie Jue, Ie Bróuk, Alue Ie Masam, Alue Ie Suum, Alue Utuen Pineung and others. However there are only a few research to discover and to discuss the geothermal prospect of Mount Seulawah Agam. Among several potential geothermal fields in Aceh, only 2 (two) are ready to be developed, namely Jaboï geothermal field in Sabang and Seulawah Agam in Aceh Besar [4].

Exploration of geothermal energy of sulphate springs has been widespread throughout the world such as the hot springs of South Solfatara area of Saint Lucia, Lesser Antilles island [5], Gonghe geothermal waters, Northwestern China [6], Groundwaters of Mt. Vulture volcano, southern Italy [7], Thermo-mineral springs of the Cerna Valley, Romania [8], Los Humeros geothermal system, Mexico [9] and Urban sandstone aquifer, Birmingham, UK. In relation to the geothermal field of Mount Seulawah Agam in Aceh Besar-Indonesia regency, the determination of reservoir depth temperatures and geothermal fluid types in Ie Seu'um manifestation area has been conducted[11], meanwhile in the Ie Jue manifestations, the determination has not been conducted. One of the first stages of the exploration of geothermal sources is to estimate the depth temperature and reservoir fluid type based on the geochemical composition. This research will cover the determination of geothermal surface fluid characteristic, geothermal chemical fluid equilibrium based on Na-K-Mg triangle diagram [12] and determining geothermal fluid type based on triangle diagram of Cl-SO₄-HCO₃ [12], whether the fluid type is chloride, sulphate or bicarbonate. The depth temperature estimation of the reservoir is based on chemical composition using Na/K geothermometer equation [12,13,14,15,16].

2. Methods and Materials

2.1. Water Sampling and Field Data Measurement
The location of the geothermal manifestation of Ie Jue is found in Lamteuba Droe Village, Seulimum Sub-district, Aceh Besar District, which is an upflow zone of Mount Seulawah Agam. Manifestations are found in the form of hot sulphate springs with hot water output and hot steam smells of sulfur. The color of the hot water produced is cloudy due to mixing with acidic clay water. There are no plants and few trees that grow outside the area of manifestation (stress vegetation). For sampling location map via satellite image (google earth) and temperature map can be seen respectively in figures 1 and 2. Before the water sample is taken, the initial measurement as field data covering point of sampling point, elevation, surface water temperature, degree acidity (pH), conductivity and total dissolved solids (TDS). The geothermal water is taken at large and high-temperature water discharge. Hot water samples were filtered using Whatman filter paper with a pore size of 0.45 μm, incorporated in a polyethylene bottle with the addition of 3N HNO₃ solution to pH = 2 (acidified), acid addition is not carried out for the cation and anion measurement.

2.2. Materials and Instruments
The materials used were demineralized water, 0.45 μm filter paper, NaCl solution, HNO₃ solution, methyl orange indicator, phenolphthalein indicator, chromate potassium indicator, sulfaver (powder kit), HCl solution, AgNO₃ solution, standard solution of potassium (1000 mg/L), sodium (1000 mg/L), calcium (1000 mg/L) and magnesium (1000 mg/L).

The instruments used are Portable pH meter and Conductometer (Schott Instrument), Portable Temperature (Fisher Scientific Traceable), Atomic Absorption Spectroscopy (AAS) instruments (Shimadzu 6200), UV-Vis Spectrophotometer (DR/2010), GPS (Garmin 62S), analytical balance,
polyethylene bottle, universal pH indicator, glove, plastic bucket, a set of titrations, spatula, hot plate and cool boxes.

2.3. Measurements and Data Processing

An analytical method for cation content (K, Mg, Ca, Na) in a geothermal water sample is carried out using AAS instrument. For the analysis of anion content of bicarbonate, chloride and sulphate, the titration method of acidimetry, argentometry (mohr) and UV-Vis spectrophotometry respectively are carried out. The content of cations and anions is input in spreadsheet version 3 Powell Geoscience Ltd. 3 September 2012 by Powell & Cumming [17]. The determination of geothermal water type is carried out by the triangle diagram of Cl-SO4-HCO3 [12], meanwhile the determination of geothermal chemical equilibrium is carried out by Na-K-Mg triangle diagram [12]. The depth temperature estimation uses the Na/K geothermometer formula with various references such as table 1. For the uncertainty measurement of cation concentration is calculated according to formula (1) [18].

\[
S_C = \frac{S_r}{m} \sqrt{\frac{1}{M} + \frac{1}{N} + \frac{(Y_c - Y_{ave})^2}{m^2 S_{xx}}}
\]

(1)

Where \(S_C\) is standard deviation of concentration, \(S_r\) is standard deviation of regression, \(m\) is slope, \(M\) is the number of replicated results, \(N\) is the number of point in the calibration curve (number of standards), \(Y_c\) is the mean response for the unknown. \(Y_{ave}\) is the mean value of \(y\) for calibration results and the quantity \(S_{xx}\) is the sum of the squares of the deviation of \(x\) values from the mean [18].

| No | Geothermometers | Equations | References |
|----|-----------------|-----------|------------|
| 1  | Na – K          | \(T = \frac{1390}{(1.750 + \log(Na/K))} - 273.15\) | Giggenbach, 1988 [12] |
| 2  | Na – K          | \(T = \frac{1217}{(1.483 + \log(Na/K))} - 273.15\) | Fournier, 1979 [13] |
| 3  | Na – K          | \(T = \frac{855.6}{(0.857 + \log(Na/K))} - 273.15\) | Truesdell, 1976 [14] |
| 4  | Na – K          | \(T = \frac{833}{(0.780 + \log(Na/K))} - 273.15\) | Tonani, 1980 [15] |
| 5  | Na – K          | \(T = \frac{1319}{(1.699 + \log(Na/K))} - 273.15\) | Arnórsson, 1983 [16] |

3. Result and Discussion

As a preliminary data, the determination of the surface geothermal properties of Ie Jue manifestations was carried out. Measurements were done in-situ with five repetitions, to obtain the average value and the value of uncertainty measurement as shown in Table 2.
Table 2. On-site characteristics of water sample for Ie Jue manifestation

| Coordinate | Elevation (m) | T<sub>water</sub> (°C) | pH       | Conductivity (mV) | TDS (mg/L) |
|------------|--------------|-------------------------|----------|-------------------|------------|
| 5° 30.414  | 95° 37.736   | 265                     | 93.55 ± 0.64 | 5.77 ± 0.04      | 85.42 ± 1.36 | 886.1 ± 3.94 |

Ie Jue manifestation was in the form of sulfuric hot springs with acidic water output (pH = 5.77 ± 0.04) and accompanied by a sulfur-containing hot vapor. The surface water temperature reached 93.55 ± 0.64 °C and the conductivity value and the TDS value were relatively high. The color of hot water that was cloudy due to mixed acidic clay. There was no vegetation surrounding the manifestation (vegetation stress).

Determination of geothermal fluid type in Ie Jue manifestation was done by measuring anion content in the geothermal water sample. The measured anion content was sulphate, bicarbonate and chloride. According to the result of anion measurement, sulphate concentration had the highest concentration level that was 480.0 ± 0.36 mg/L compared with the concentration of bicarbonate and chloride that was respectively equal to 36.0 ± 0.26 mg/L and 4.99 ± 0.10 mg/L.

Based on the plot results in the triangular diagram of Cl-SO<sub>4</sub>-HCO<sub>3</sub> geothermal fluid manifestation Ie Jue had a water sulphate fluid type (Figure 3). This type of fluid could be interpreted as steam-heated water which was characterized by an acidic pH and makes its ability to dissolve the surrounding rocks [19].

![Figure 3](image-url)

**Figure 3.** Cl-SO<sub>4</sub>-HCO<sub>3</sub> ternary diagram of the geothermal water for Ie Jue manifestation.

![Figure 4](image-url)

**Figure 4.** Na-K-Mg ternary diagram of the geothermal water for Ie Jue manifestation.

The Na-K-Mg triangle diagram is an indicator to explain the fluid equilibrium at a depth of the reservoir. The result of the measurement of cation concentration from a geothermal water sample of Ie Jue manifestation is exhibited by Table 3.

Table 3. The chemical concentration (cations) of a water sample for Ie Jue manifestation.

| No | Cations | Concentrations (mg/L) ± S<sub>c</sub> |
|----|---------|--------------------------------------|
| 1  | Sodium  | 54.82 ± 0.26                        |
| 2  | Potassium | 111.04 ± 0.11                   |
| 3  | Calcium | 9.33 ± 0.11                         |
| 4  | Magnesium | 8.62 ± 0.01                      |

<sub>S<sub>c</sub> standard deviation of concentration</sub>
The result of the Na-K-Mg triangle diagram based on cation content can be seen in Figure 4. The manifestation of *Ie Jue* is in immature water state. This condition indicated that the influence of surface water mixed with the fluid during the formation of hot springs. In addition, hot water is also affected by the interaction between the water and the rocks in the heat condition [20].

Geothermometer is a form of equation used to estimate the subsurface temperature of the earth (reservoir). Chemical equilibrium to temperature is strongly influenced by the concentration of cations used as temperature prediction of a reservoir [19]. So far geothermometer equations have been proposed by several different authors. The result of calculation from some geothermometer to the geothermal manifestation of *Ie Jue* can be seen in Table 4.

Although it had been calculated by many geothermometer equations, all the results gave the same result where the temperature is above 300 °C. Among those equations, only Fournier (1979) and Giggenbach (1988) geothermometers are best used for high-temperature reservoirs [19]. In this study, the estimated temperature of the reservoir depth of *Ie Jue* manifestation is 690-761 °C using the geothermometer equation Na/K Giggenbach (1988) and Fournier (1979).

| No | Geothermometers                        | Temperatures Estimation (°C) |
|----|--------------------------------------|-----------------------------|
| 1  | Na/K Giggenbach, 1988 [12]           | 690                         |
| 2  | Na/K Fournier, 1979 [13]             | 761                         |
| 3  | Na/K Truesdell, 1976 [14]            | 1280                        |
| 4  | Na/K Tonani, 1980 [15]               | 1592                        |
| 5  | Na/K Arnorsson, 1983 [16]            | 1086                        |

Based on reservoir depth temperatures obtained through geothermometer calculations, it is known that *Ie Jue* manifestations including high-temperature geothermal system (high enthalpy) are characterized by temperature gain > 225 °C, thus suitable for power plant development [21]. Based on this survey, it is estimated that the geothermometer temperature of *Ie Jue* manifestation ranged from 690-761 °C. The accuracy of this method of hot water geothermometer needs to be verified further with the gas geothermometer because the area of the *Ie Jue* manifestation also found a steam source of fumarole.

4. Conclusion

Geothermal fluid in *Ie Jue* manifestation has sulphate spring type based on triangle Cl-SO₄-HCO₃ and acidic diagram (pH = 5.77 ± 0.04). Manifestation of the *Ie Jue* is in immature water state based on Na-K-Mg triangle diagram, this condition indicates that the influence of surface water mixed with fluid at the time of hot spring formation. Estimated temperature of the reservoir depth of *Ie Jue* manifestation is 690-761 °C. Based on geothermometer calculations, *Ie Jue* manifestations can be identified as high-temperature geothermal (high enthalpy) systems, making them suitable for power plant development.

5. References

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