The estimation of geothermal reservoir temperature using geothermometer equation in Cubadak area, Pasaman regency, West Sumatra, Indonesia

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Abstract. A research to estimate geothermal reservoir temperature in Cubadak Area, Pasaman Regency, had been carried out as one of the early stages for geothermal system development in West Sumatera. 100 ml of fluids was examined from 20 hot springs in the vicinity of Cubadak area. Estimated reservoir temperature is calculated using geothermometer equation by determining Na, K, Ca, and SiO$_2$ concentration. The Na, K and Ca concentration are measured by Atomic Absorption Spectroscopy (AAS), and the SiO$_2$ concentrations is computed by Visible Spectroscopy. The results of this research shows that a suitable geothermometer in Cubadak Area is a Na-K geothermometer. Estimated average reservoir temperature ranges between 222.6°C and 234.9°C, computed from Na-K geothermometer equations developed by Fournier and Giggenbach.

1. Introduction

1.1 Geothermal of Cubadak Area

Geothermal is a natural source of heat derived from the interaction of hot rocks (magma) with groundwater beneath the earth's surface. The interaction results are trapped somewhere beneath the surface of the earth called a geothermal reservoir. Geothermal reservoirs can be classified into hydrothermal reservoirs, geopressed reservoirs, hot dry rock reservoirs, and magma reservoirs. Geothermal reservoir has a high temperature above 150°C [1]. Reservoir hydrothermal is the most widely reservoir in Indonesia. This reservoir can produce geothermal manifestations like hot springs.

The main source of energy used in Indonesia is fossil fuel. This energy is explored on a large scale to meet the needs of increasing human energy. This causes Indonesia's energy reserves become decrease. Therefore, we need to look for alternative energy to overcome the problem and one of them is geothermal energy. Nowadays, Indonesia has 265 geothermal areas with a total potential of 28.5 GW and one of them is in Sumatra region. West Sumatra is estimated to have geothermal energy 1,956 Megawatts (MW) of 27,670 MW of Indonesia's geothermal in 2008 calculations. Geothermal potential in West Sumatra is still largely unfilled as in Cubadak, Lubuk Sikaping, Simisoh and Bonjol areas [2]. Cubadak geothermal area is one of West Sumatra's geothermal potential areas in the District of Duo Koto, Pasaman Regency, West Sumatra, located at 99° 55' 45" - 100° 02' 14" BT and 0° 22' 36" - 0° 13' 58" LS. Potential of geothermal in the Cubadak area is identified from the emergence of silica sinter around Cubadak’s hot springs with a thickness of more than 10 cm [3]. The components
of the Cubadak geothermal system in the form of clay and has a very low resistivity value. The reservoir zone has an intermediate resistivity value and has a reservoir upper limit from a height of 250 m to 500 m above the sea level [4].

1.2 Geothermometer

Estimation of geothermal reservoir temperature is an important step for the development of geothermal systems. This research uses geothermometer equations to estimate reservoir temperature in Cubadak Area, Pasaman Regency, West Sumatera. Geothermometer equations can be used to determine the characteristics of the reservoir through the relationship of chemical composition to the fluid to temperature. It has been developed geochemical-based empirical geothermometer equations [5]. The equation has been tested on several wells in the world and found its minimum error. Geochemical methods are used based on the development of an empirical geothermometer involving a number of chemical elements such as Na, K, Ca, Mg, and SiO₂. The concentrations of Na, K, Ca, Mg, and SiO₂ can be determined by the Atomic Absorption Spectrophotometer (AAS) method then incorporated into the geothermometer formulas. The temperature calculated using the geothermometer formulas has a rms error value <5%.

The estimation of geothermal reservoir in Panti area, Pasaman, had been evaluated from 5 (five) hot springs using geothermal equation involving Na, K, Ca, Mg, and SiO₂. The suitable geothermometer for Panti area is Na-K-Ca geothermometer with calculation result of average reservoir estimation is 548.9°C and has a potential energy of more than 100 MW [6].

Geothermometer equations in general can be divided into silica, Na-K, and Na-K-Ca geothermometer. Silica geothermometer is better used in research areas that have silica sinter deposits. Some researchers have developed some geothermometer equations which its application is highly dependent on fluid conditions and silica precipitate types [7]. The equation shown in Table 1 with C is the concentration of silica (mg / L).

| Geothermometer Geothermometer Equations | Reference |
|----------------------------------------|-----------|
| Quartz-no steam loss T = 1,309 / (5.19 – log C) – 273.15 | Fournier (1977) |
| Quartz-maximum steam loss at 100°C T = 1,522 / (5.75 - log C) – 273.15 | Fournier (1977) |
| Quartz T = 42.198 + 0.28831C – 3.6686 x 10⁻⁴ C² + 3.1665 x 10⁻⁷ C³ + 77.034 log C | Fournier and Potter (1982) |
| Quartz T = 53.500 + 0.11236C – 0.5559 x 10⁻⁴ C² + 0.1772 x 10⁻⁷ C³ + 88.390 log C | Arnorsson (1985) |
| Chalcedony T = 1,032 / (4.69 - log C) – 273.15 | Fournier (1977) |
| Chalcedony T = 1,112 / (4.91 - log C) – 273.15 | Arnorsson (1983) |
| Cristobalite T = 1,000 / (4.78 - log C) – 273.15 | Fournier (1977) |
| Opal T = 781 / (4.51 - log C) – 273.15 | Fournier (1977) |
| Amorphous silica T = 731 / (4.52 - log C) – 273.15 | Fournier (1977) |

Na-K geothermometer can be applied to chloride water reservoir with a large temperature of 180°C. This geothermometer is poor at temperatures smaller than 100°C and is rich in Ca or widely associated with travertine deposits [7]. Table 2 shows the development of the Na K geothermometer equations.

| Geothermometer Geothermometer Equations | Reference |
|----------------------------------------|-----------|
| T=[1,217 / (1.483 + log (Na / K))]- 273.15 | Fournier (1979) |
| T=[1,390 / (1.750 + log (Na / K))]- 273.15 | Giggenbach(1988) |
Na-K-Ca geothermometer equations was developed by Fourier and Truesdell in 1973 to complete the deficiencies of the Na-K geothermometer method. Na-K-Ca geothermometers are commonly used at lower temperatures and water rich in Ca ions [8] Equation formula of Na-K-Ca geothermometer in Eq. (1)

\[ T = \frac{1.647}{\log([\text{Na}]) + (\log([\text{Ca}]/[\text{Na}]) + 2.06) + 2.47} - 273.15 \]  

(1)

2. Research Method
This research uses sample of hot springs at 20 points taken in the vicinity of Cubadak, Pasaman, West Sumatra. 17 samples were taken at Cubadak (A-M and Q-T) and 3 samples in Talu (N-P), that is located about 15 km from Nagari Cubadak. The location of sampling can be seen in Figure 1. The early measurement is surface temperature and pH. Surface temperature is measured by digital thermometer and pH is measured by pH meter. The sample is taken as much as 100 ml and put into the vial glass bottles. The sample was then transported to laboratory to measure the concentration of Na, Ca, K with Atomic Absorption Spectroscopy (AAS) and measurement of SiO$_2$ concentration by using Visible Spectroscopy.

![Figure 1. Location of sampling](image)

The concentration of Na, Ca, K and SiO$_2$ obtained was applied to the geothermometer equation to estimate the temperature of the geothermal reservoir in the area. From the concentration of Na, Ca, K and SiO$_2$, the pH of the sample, the surface temperature and the reservoir temperature obtained were analyzed for the geothermal potential in Cubadak, Pasaman, West Sumatera. It also analyzed suitable geothermometer equation.

3. Results and Discussion
The measurement of Na, K, Ca and SiO$_2$ can be found at Table 4.2. The concentrations of Ca for each sample are not too high or smaller than 50 ppm, that means geothermometer Na-K-Ca is unsuitable for the research area, because Na-K-Ca geothermometer is fit for research areas that have a high concentration or greater than 50 ppm [7]. The concentrations of SiO$_2$ are not too high or smaller than100 ppm makes silica geothermometer also unsuitable for use in the Cubadak area. The normal silica concentrations in geothermal fluid ranges from 100 ppm to 300 ppm, that is much different from the concentration of silica obtained in the study area [7]. Therefore, silica geothermometer is not acceptable for use in the study area. The appropriate geothermometer used in the study area is the Na-K geothermometer.
Table 3 shows that geothermal reservoir temperature estimation using geothermometer equations developed by Fournier and Gigenbach is on average in medium temperature reservoir range. Geothermal reservoir is divided into low temperature (small from 125°C), medium temperature (125°C-225°C) and high temperature (large from 225°C) [8]. In the L and M regions of the geothermal springs in the Sawah Mudik 1 and 2, there are different concentrations of Na and K from other regions causing the reservoir temperature estimation in the 2 regions be too low and too high. It is suspected because the hot springs have been mixed with river water or groundwater around it, that affect the concentration obtained.

Geothermal reservoirs of moderate and high temperatures can be utilized as geothermal power plants. Therefore, Cubadak geothermal has great potential to be developed as geothermal power plant. Geothermal potential in Cubadak is indicated ranges from 50 MW to 100 MW. This is influenced by the existence of geological activities such as volcanism and tectonism in the area. Geothermal volcanic activity of Cubadak is influenced by Mount Talamanu which is located about 34.4 km from Cubadak area. Tectonic activity is influenced by the Sumatera Fault derived from subduction of the Indian-Australian plate and the Eurasian plate about 45.6 million years ago. Indonesia's geothermal system is divided into 3 main parts, namely volcanic geothermal system with high temperatures that has a potential energy of 50 MW to a large of 100 MW, volcanic-tectonic geothermal system with moderate until high temperature has energy potential ranges from 50 MW until bigger than 100 MW, and non-volcanic geothermal system with low until moderate reservoir temperature has energy potential of around 50 MW [9]. According [10] geothermal area of Cubadak is suspected to have geothermal potential around 70 MW.

Table 3. Estimation of geothermal temperature of Cubadak area

| Code | Information          | Na (ppm) | K (ppm) | Ca (ppm) | SiO2 (ppm) | Fournier | Giggenbach |
|------|----------------------|----------|---------|----------|------------|----------|------------|
| A    | Cubadak 1            | 583.96   | 39.43   | 20.26    | 22.87      | 185.9    | 202.8      |
| B    | Cubadak 2            | 545.06   | 37.92   | 18.34    | 24.24      | 187.7    | 204.9      |
| C    | Cubadak 3            | 582.79   | 42.67   | 19.27    | 27.10      | 191.7    | 208.6      |
| D    | Cubadak 4            | 547.61   | 36.04   | 17.67    | 23.58      | 183.6    | 201.0      |
| E    | Cubadak 5            | 438.06   | 27.75   | 6.61     | 24.40      | 180.8    | 198.3      |
| F    | Cubadak 6            | 610.07   | 40.77   | 14.61    | 26.52      | 184.7    | 202.1      |
| G    | Cubadak 7            | 558.06   | 39.37   | 15.74    | 21.97      | 188.8    | 206.0      |
| H    | Cubadak 8            | 291.21   | 39.98   | 16.82    | 20.25      | 245.7    | 258.9      |
| I    | Cubadak 9            | 558.85   | 42.17   | 18.39    | 17.33      | 194.0    | 210.8      |
| J    | Cubadak 10           | 551.03   | 42.50   | 18.67    | 18.61      | 195.7    | 212.4      |
| K    | Cubadak 11           | 586.89   | 43.01   | 19.18    | 24.37      | 191.7    | 208.7      |
| L    | Sawah Mudik 1        | 170.89   | 9.30    | 0.91     | 21.98      | 169.9    | 188.0      |
| M    | Sawah Mudik 2        | 19.21    | 38.87   | 0.91     | 23.96      | 760.8    | 689.5      |
| N    | Talu 1               | 129.33   | 20.40   | 2.84     | 32.20      | 259.4    | 271.5      |
| O    | Talu 2               | 281.12   | 19.40   | 3.15     | 29.02      | 187.2    | 204.4      |
| P    | Talu 3               | 190.24   | 13.90   | 2.69     | 25.2       | 191.5    | 208.5      |
| Q    | Cubadak 12           | 323.70   | 21.31   | 50.50    | 25.88      | 183.6    | 201.0      |
| R    | Cubadak 13           | 177.40   | 10.04   | 46.85    | 28.60      | 172.6    | 190.6      |
| S    | Cubadak 14           | 355.08   | 28.68   | 55.23    | 38.69      | 199.3    | 215.8      |
| T    | Cubadak 15           | 234.78   | 18.79   | 56.85    | 30.59      | 198.6    | 215.2      |
4. Conclusions

Cubadak area, Pasaman Regency has the potential of geothermal system. Geothermal reservoir in Cubadak is estimated in medium temperature with average ranges between 222.6°C and 234.9°C, computed from Na-K geothermometer equations developed by Fournier and Giggenbach. Geothermal potential in Cubadak area is influenced by volcanic activity of Mount Talamau and tectonic fault of Sumatra.

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