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Determination of Geothermal Fluid Characteristics in Pawan and Pendalian IV Koto Villages, Rokan Hulu Regency, Riau Province Using Geochemical Methodss

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Abstract: Geothermal in Pawan and Pendalian IV Koto Villages is one of the post-volcanic geothermal areas in the Rokan Hulu Regency. This study aims to determine the characteristics of geothermal fluids and estimate reservoir temperature based on geothermometer estimation. The research method used in the study consisted of several stages, namely field data collection and fluid geochemical analysis. The research results from 12 hot springs plotted on the Cl-Li-B triangle diagram show that all hot water samples are dominated by Cl, indicating that the hot springs are far from the geothermal reservoir. The Cl-SO_4-HCO_3triangle diagram shows that all of the hot springs are bicarbonate water types dominated by HCO_3. The Na-K-Mg triangle diagram shows that all fluid samples are in the immature water area, which indicates that the fluid has undergone a reaction with other elements or the influence of meteoric water is quite dominant. The results of calculations with a geothermometer, the estimated reservoir temperature in the geothermal area is in the range of 160.69°-176.76°C, which is included in the medium-temperature reservoir system. Geothermal in this area can be used as the geothermal potential for developing geothermal power plants.

Keywords: Geochemistry; Rokan Hulu; Geothermal; Fluid geothermometer

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Introduction

Indonesia is located between three plates, namely the Pacific, Indo-Australian, and Eurasian plates (Utami, 1999). The collision of the Indo-Australian Plate and the Eurasian plate resulted in hills and volcanic mountains in Sumatra and Java. Indonesia has enormous geothermal potential globally because it is one of the countries that is passed by the ring of fire (Wahyuningsih, 2005). The world's geothermal potential in Indonesia is 40%, with a total energy reserve of 28 GW (Suhartono, 2012). Geothermal energy potential in Indonesia is spread over 285 points along the volcanic arc of the Indonesian region.

Geothermal systems are formed because heat transfer from a source is flowed to the surroundings by conduction and convection (Lawless et al., 1995; Indratmoko et al., 2009). Convection heat transfer occurs because of the contact of water with a heat source which causes the emergence of hot springs in various areas (Hochstein et al., 1996). The existence of geothermal potential can usually be identified by signs that appear to the surface or are called manifestations (Saptadji, 2009). Geothermal manifestations on the surface such as hot springs, hot mud puddles, geysers, fumaroles, silica sinter, warm soil, steamy ground surface, and hot pools.

Rokan Hulu Regency is one area with geothermal potential in Pawan Village and Pendalian IV Koto Hot Water Village. The existence of geothermal potential in this area is marked by the manifestation of hot springs that have been used as tourist attractions for hot springs. Research on the geochemical characteristics of hot springs and estimation of geothermal reservoir

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temperatures in these two locations needs to be carried out as a preliminary study to determine geothermal potential in Rokan Hulu Regency.

Geochemistry is one method of geothermal exploration to study the characteristics of geothermal fluids. This method can be used through the surface's geothermal manifestation, such as hot springs that appear on the surface. Jasmita (Jasmita and Putra, 2020) used a fluid triangle diagram to study the fluid characteristics of hot springs in Sibanggor Tonga, Mandailing Natal Regency. Based on the Cl-SO_4-HCO_3 diagram, all samples of hot springs are sulfate-chloride type. The Na-K-Mg triangle diagram concludes that all fluid samples are in immature water. The fluid has undergone a reaction with other elements when it reaches the surface. The Cl-Li-B triangle diagram shows that the hot springs come from a fluid source that is far from the reservoir. This paper presents the results of the geochemical method to determine geothermal potential in Rokan Hulu Regency, especially in Pawan Village and Pendalian IV Koto Hot Water Village.

Method

The material used in this study is water from hot springs in 4 pools with 12 sample points located in Pawan and Pendalian IV Koto villages. Each sample was measured pH and surface temperature. The pH was measured by a digital pH meter, and a digital thermometer measured temperature. Measurements of pH and surface temperature were carried out directly on site. Once the pH and surface temperature were measured, the samples were collected using bottles to be analyzed in the laboratory

Samples were characterized by acid-base alkalinity titration methods, Visible Spectroscopy, and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) which is capable of measuring metal concentrations in hot water. From the analysis of hot water samples using ICP-AES, the concentration values of Li, B, Na, K, Mg metals were obtained. From Visible Spectroscopy, we obtained the concentration of SO_4, Cl, Silica, and the acid-base alkalinity titration method has obtained the concentration of HCO_3. Then the concentration value is substituted into Equation 1 to Equation 4 to get the percentage value of Cl, Li, B. The concentration value is also substituted into Equation 5 to Equation 8 to get the percentage value of Cl, SO_4, HCO_3. The concentration values were also substituted into Equations 9 to 12 to get the percentages of Na, K, and Mg percentages. The percentage results are then plotted on a ternary triangle diagram. The origin, dilution, type of hot water, and geothermal fluid equilibrium will be analyzed based on the diagram. The SiO_2 concentration value is entered into the appropriate geothermometer equation to estimate the temperature of the geothermal reservoir. The data is then analyzed and linked to geothermal potential based on fluid characteristics and geothermal reservoir temperature.

$$S = \frac{[Cl]}{100} + [Li] + \frac{[B]}{4} \quad \text{......... (1)}$$

$$\%Cl = \frac{[Cl]}{S} \quad \text{......... (2)}$$

$$\%Li = \frac{[Li]}{S} * 100 \quad \text{......... (3)}$$

$$\%B = \frac{[B]}{4} * S * 100 \quad \text{......... (4)}$$

$$S = [Cl] + [SO_4] + [HCO_3] \quad \text{......... (5)}$$

$$\%Cl = \left(\frac{[Cl]}{S}\right) * 100 \quad \text{......... (6)}$$

$$\%SO_4 = ([SO_4]/S) * 100 \quad \text{......... (7)}$$

$$\%HCO_3 = ([HCO_3]/S) * 100 \quad \text{......... (8)}$$

$$S = [Na] + 10[K] + 1000[Mg]^{1/2} \quad \text{......... (10)}$$

$$\%Na = [Na]/S * 100 \quad \text{......... (11)}$$

$$\%K = \left(\frac{10[K]}{S}\right) * 100 \quad \text{......... (12)}$$

$$\%Mg = \left(\frac{1000[Mg]^{\frac{1}{2}}}{S}\right) * 100 \quad \text{......... (13)}$$

Result and Discussion

Measurement Data

The surface temperature and pH of hot springs are in the range of 42.6°C-56.5 °C, while the pH is 6.1 – 6.2 (neutral). It is indicated that interaction between acid fluids associated with the geothermal system is due to sedimentary rocks, resulting in neutralization which forms neutral hot springs. The data from the measurement of surface temperature and pH can be seen in Table 1.

Table 1. Surface temperature and pH of hot water

Sample	T (°C)	pH
Pawan village		
K1 AP	56.50	6.50
K1 AT	56.50	6.40
K1 AK	56.50	6.50
K2 AP	46.30	6.70
K2 AT	46.30	6.60
K2 AK	46.30	6.70
Pendalian IV Koto village		
K1 AP	42.60	6.80
K1 AT	42.60	6.90
K1 AK	42.60	6.90
K2 AP	43.80	6.10
K2 AT	43.80	6.90
K2 AK	43.80	6.70

The results of the measurement of metal analysis in the study area are shown in Table 2. Each sample with the same element has a different concentration value. This is because each geothermal system has its own characteristics. Each geothermal manifestation that reaches the surface experiences different reactions, and the nature of the rocks it passes through is also different from one another (Saptadji, 2009).

Table 2. Metal concentration data of hot springs

Sample	Concentration ppm (mg/L)							
	Cl	Li	B	SO_4	HCO_3	Na	K	Mg
Pawan village								
K1 AP	20	0.0675	0.0005	23.1	125	1.05	1.35	0.67
K1 AT	10	0.0664	0.0001	22	163	1.11	1.22	0.86
K1 AK	16	0.0665	0.0001	20.6	175	1.21	1.53	0.70
K2 AP	22	0.0712	0.0002	14	175	0.98	1.22	0.65
K2 AT	14	0.0535	0.0001	14.9	187	0.87	1.30	0.70
K2 AK	16	0.0717	0.0003	17.9	188	0.97	134	0.78
Pendalian IV Koto village								
K1 AP	20	0.0734	0.0001	19.4	188	1.24	1.18	0.46
K1 AT	10	0.0765	0.0001	18	113	1.05	1.21	0.76
K1 AK	21	0.0786	0.0001	16.7	125	1.08	1.20	0.63
K2 AP	18	0.0834	0.0001	23	125	1.02	1.05	0.56
K2 AT	22	0.0817	0.0001	22	187	0.98	1.13	0.63
K2 AK	20	0.0855	0.0002	20.7	125	0.87	0.97	0.55

Cl-Li-B Triangle Diagram

The results of plotting the data on the Cl-Li-B triangle diagram indicate that samples were at the Cl concentration (Figure 1). Thus, the hot water that rises to the surface is a fluid that comes directly from a heat source with minimal cooling by rocks around the fluid flow (Nicholson, 1993). All samples are far from the elemental Li concentration, which indicates that the hot springs are far from the heat source of the geothermal system. A high Cl element indicates that the fluid flow process occurs in an up-flow or reasonably close to the main geothermal fluid flow (Aribowo and Nurohman, 2012).

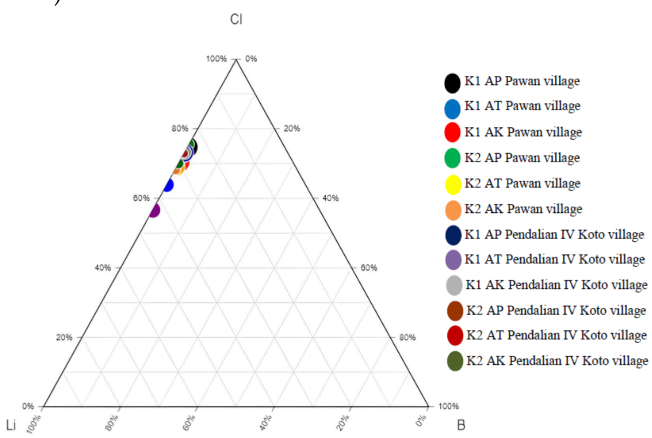

Figure 1. Cl-Li-B triangle diagram.

The Cl-Li-B triangle diagram shows that 12 hot spring sample points are far from the element Li in (Figure 1). Thus, the hot springs originate far from the heat source of the geothermal system. Li is easily absorbed by secondary minerals such as chlorite, quartz, and clay, so the farther the distance of fluid transfer to the surface, the concentration of Li element will decrease. All samples are far from element B, as seen in the Cl-Li-B diagram in (Figure 1), which indicates that during the passage of the hot springs from the hot springs to the surface, there is a slight dilution by the rock through which the hot water flows (Giggenbach, 1991). The concentration of element B in solution is an element that is difficult to react to and indicates that there is little geothermal association with sedimentary rocks rich in organic matter. The washing process by side rocks in the form of acidic igneous rocks causes the low content of element B.

The ratio of low B/Li (Table 2) indicates that the research area is into the up-flow zone of geothermal fluid flow from the geothermal system, which causes a decrease in the content of element B because it is absorbed into sedimentary rocks. This indicates that the hot earth fluid flows laterally or sideways, mixing occurs with groundwater, and conductive cooling before reaching the surface (Nicholson, 1993). The geothermal fluid that comes out of the surface in an outflow indicates that the fluid in the area is dominated by water. Geothermal manifestations in the form of hot springs in Pawan and Pendalian IV Koto Villages have a pH of 6.1-6.9, which is neutral, which strengthens that the geothermal system in the area is dominated by water.

Cl-SO_4-HCO_3 Triangle Diagram

To determine the type of geothermal fluid, the chemical data used are the elements Cl (chloride), SO_4 (Sulfate), and HCO_3 (bicarbonate), whose percentages have been calculated. The percentage results are then plotted into a Cl-SO_4-HCO_3triangle diagram.

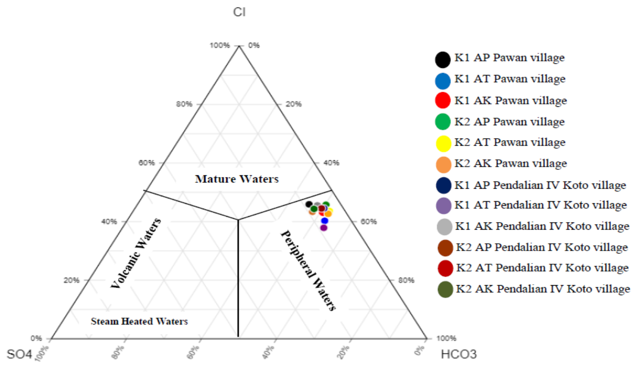

Figure 2. Cl-SO_4-HCO_3 triangle diagram.

Hot springs from 12 sample points contain HCO_3 (Bicarbonate) which is more dominant than Cl (Chloride) and SO_4 (Sulfate). The Cl-SO_4-HCO_3 triangle diagram (Figure 2) shows that the 12 hot spring sample points belong to the bicarbonate water type in the peripheral waters zone. This is consistent with the pH of the hot springs in the study area, which is around 6.1-6.9 (neutral) (Table 1). This shows that geothermal fluid occurs when the fluid mixing process comes from a heat source with meteoric water below the surface. The geothermal fluid experiences condensation of steam and gas into the water. The surface then reappears to the surface with a higher content of bicarbonate (HCO_3) than sulfate (SO_4) and chloride (Cl). The emergence of hot springs on the surface is estimated as an outflow, which indicates that hot springs are influenced by surface water when traveling to the surface. The fluid type in the chloride water zone indicates that the hot water source comes from the reservoir. In contrast, the fluid in the sulfate water indicates that the hot water is directly related to volcanism (Nicholson, 1993).

Na-K-Mg Triangle Diagram

The concentration of elements sodium (Na), potassium (K), and magnesium (Mg) are dissolved substances that reflect the environment in a state of equilibrium or are reactive. Therefore, they can be used to determine the equilibrium of geothermal fluids because these elements are formed due to temperature changes.

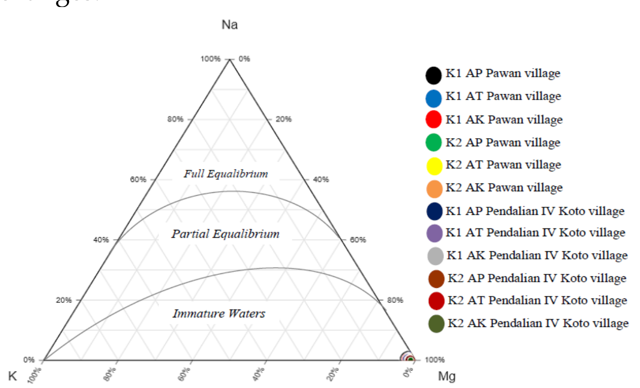

Figure 3. Na-K-Mg triangle diagram.

The Na-K-Mg triangle diagram can be used to determine the fluid balance of a geothermal reservoir and to determine a suitable geothermal geothermometer for a research area (Giggenbach, 1991). Based on the Na-K-Mg triangle diagram in (Figure 3), it is found that all hot water samples are in the immature water section and have higher Mg levels than K and Na elements. The samples in the immature water area, as shown in Figure 3) indicate that the hot springs in the study area have not yet reached equilibrium or have experienced reactions with other elements when they reach the surface. The high Mg content compared to the Na and K levels indicates that geothermal water has been mixed with groundwater with a higher Mg concentration (Murray, 1996; Kühn, 2004).

The Na-K-Mg triangular diagram depicts the equilibrium of geothermal fluids. Based on the Na-K-Mg equilibrium analysis, it can be seen that all hot water samples are near Mg. This shows that geothermal water is included in immature water. This indicates that although the output water is chloride water from reservoir water, it has been mixed with water near the surface.

The concentration of Mg in geothermal fluids comes directly from geothermal reservoirs without any dilution, which is 0.001-0.1 ppm (Nicholson, 1993). The concentration of Mg in the study area was 0.46-0.86 mg/L (more than 0.1 ppm), indicating that the geothermal reservoir fluid in the study area has experienced much mixing with groundwater when it reaches the earth's surface.

The immature water conditions also indicate that the reservoir rock is located at high temperature and pressure conditions, diluted by surface water before reaching the surface (Aribowo and Nurohman, 2012). The surface temperature at the research site ranged from 42.6-56.5 °C. The immature water area indicates that geothermal fluid mixes with colder surface water, causing the temperature of the geothermal fluid that reaches the surface to decrease.

All samples contained in the immature waters cause a better estimate of the geothermal reservoir temperature using the silica geothermometer equation. This is based on research that states that the Na-K geothermometer is more suitable for samples close to the entire equilibrium area (Zhang *et al.*, 2015). The K-Mg geothermometer is more suitable for use in immature water areas. A good reservoir temperature estimate still has to consider other elements present in the reservoir fluid, especially fluids that have experienced dilution from the state of the geothermal manifestation (Aribowo, 2011). These considerations are based on the nature of geothermal manifestations for using geothermometer equations such as silica geothermometers.

Fluid interaction with hot rock controls the potassium (K) element, and it can be seen that the potassium (K) concentration value is 0.97-1.53 mg/L. This small concentration of K indicates that the fluid flow moves slowly from the heat source to the surface. Therefore, it can be concluded that the geothermal system in Pawan and Pendalian IV Koto villages undergoes a conductive cooling process.

Judging from the percentage of Na from 12 sample points of hot springs in Pawan Village and Pendalian IV Koto, the concentration was 0.87-1.24 mg/L. In geothermal reservoir systems that have high temperatures (<250°C), the sodium (Na) content ranges from 200-2000 ppm (Nicholson, 1993). Na is an element that is controlled by fluid interactions with hot rocks in the geothermal system. The low Na content indicates the reservoir temperature is below 250 °C.

Estimation of Geothermal Reservoir Temperature

The geothermal system in Pawan and Pendalian IV Koto villages, seen from the results of the Na-K-Mg triangle plot, is in an immature water area where the reservoir fluid has experienced mixing with shallower water with a low silica concentration on its way to the surface (Giggenbach, 1991). To see the estimated temperature of the geothermal reservoir can use the calculation of the silica geothermometer (SiO_2). Silica geothermometers are more suitable for use in geothermal fluids located in immature water areas. This geothermometer equation to see the reservoir temperature must also consider the properties of geothermal manifestations. This geothermometer was developed by Arnorsson (Arnórsson, 1985) and is good for use in the manifestation of warm springs. Based on the equation of the quartz geothermometer at 12 hot spring sample points, the estimated reservoir temperature in the study area is in the range of 156.08°-176.76°C with an average reservoir temperature estimate of 166.90°C. This indicates that the temperature of the geothermal reservoir is in a system containing medium-temperature fluids (Saptadji, 2009). Geothermal fluids with moderate temperatures occur because geothermal water experiences dilution or mixing with meteoric water when it reaches the earth's surface. Geothermal fluids with medium temperatures (125°-225°C) and high temperatures (>225°C) can be used as geothermal power plants(Hochstein and Browne, 2000).

Conclusion

This study shows that the geothermal surface temperature in these manifestations is 42.6°C-56.5°C with a pH of 6.1-6.9 (neutral). The hot water fluid found in the research area of Pawan Village and Pendalian IV Koto is chloride water fluid. The hot springs in Pawan and Pendalian IV Koto villages have a bicarbonate water content and are located in the peripheral water zone. The results of the Na-K-Mg triangle plot of the hot spring in the immature water area indicate that the geothermal fluid in the study area has not reached equilibrium or has been mixed with other elements when it reaches the earth's surface. The calculation results of the quartz geothermometer show the reservoir temperature estimation in the range of 160.69°-176.76°C. The reservoir temperature estimation in the geothermal area of Pawan Village and Pendalian IV Koto is at moderate temperature. The results of this study provide information to local governments that the geothermal system in Pawan and Pendalian IV Koto Villages has the geothermal potential for the development of geothermal power plants.

References

Aribowo, Y. (2011). Prediksi Temperatur Reservoar Panasbumi dengan Menggunakan Metoda Geotermometer Kimia Fluida. *Teknik,* 32(3), 234–238. https://doi.org/10.14710/teknik.v32i3.1743

Aribowo, Y. and Nurohman, H. (2012). Studi geokimia air panas area prospek panasbumi gunung kendalisodo kabupaten semarang. *Teknik,* 33(1), 32–36. https://doi.org/10.14710/teknik.v33i1.3793

Arnórsson, S. (1985). The use of mixing models and chemical geothermometers for estimating underground temperatures in geothermal systems. *Journal of Volcanology and Geothermal Research,* 23(3-4), 299-335. https://doi.org/10.1016/0377-0273(85)90039-3

Giggenbach, W. F. (1991). Chemical techniques in geothermal exploration. *Application of Geochemistry in Geothermal Reservoir Development*, 119–144. Retrieved from https://eurekamag.com/research/018/550/018550955.php

Hochstein, M. and Browne, P. R. (2000). Surface manifestations of geothermal systems with volcanic heat sources. *Encyclopedia of Volcanoes,* 1, 835–855.

Hochstein, M. P., Ovens, S. A. and Bromley, C. (1996). Thermal springs at hot water beach (Coromandel Peninsula, NZ). *Proceedings 18th NZ Geothermal Workshop*, New Zealand.

Indratmoko, P., Nurwidyanto, M. I. and Yulianto, T. (2009). Interpretasi Bawah Permukaan Daerah Manifestasi Panas Bumi Parang Tritis Kabupaten Bantul DIY dengan Metode Magnetik. *Berkala Fisika,* 12(4), 153–160. Retrieved from https://ejournal.undip.ac.id/index.php/berkala_fisika/article/view/2924

Jasmita, M. and Putra, A. (2020). Identifikasi Karakteristik Mata Air Panas Bumi di Sibanggor Tonga Kabupaten Mandailing Natal Menggunakan Diagram Segitiga Fluida. *Jurnal Fisika Unand,* 9(4), 428–435. https://doi.org/10.25077/jfu.9.4.428-435.2020

Kühn, M. (2004). *Reactive flow modeling of hydrothermal systems* Berlin, Springer Science & Business Media.

Lawless, J. V., White, P. J., Bogie, I. and Andrews, M. J. (1995). Tectonic features of Sumatra and New Zealand in relation to active and fossil hydrothermal systems: a comparison. *Proceedings of the PANCRIM Congress*, Auckland.

Murray, K. S. (1996). Hydrology and geochemistry of thermal waters in the Upper Napa Valley, California. *Groundwater,* 34(6), 1115–1124.

Nicholson, K. (1993). *Geothermal Systems*, Springer.

Saptadji, N. M. (2009). Karakterisasi reservoir panas bumi. *Training Advanced Geothermal Engineering*, 6–17.

Suhartono, N. (2012). Pola sistim panas dan jenis geothermal dalam estimasi cadangan daerah Kamojang. *MTG,* 5(2). Retrieved from http://jurnal.upnyk.ac.id/index.php/mtg/article/view/246

Utami, P. (1999). Pemanfaatan Energi Panasbumi Secara Langsung. *Energi*.

Wahyuningsih, R. (2005). *Potensi dan wilayah kerja pertambangan panas bumi di Indonesia*. Bandung, Badan Geologi.

Zhang, X., Guo, Q., Li, J., Liu, M., Wang, Y. and Yang, Y. (2015). Estimation of reservoir temperature using silica and cationic solutes geothermometers: a case study in the Tengchong geothermal area. *Chinese Journal of Geochemistry,* 34, 233–240. http://dx.doi.org/10.1007/s11631-015-0037-7