Analysis of fluid characteristics and estimation of geothermal reservoir temperature in Kaleosan Area, North Minahasa Regency

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Abstract. The appearance of manifestation characterizes the existence of geothermal potential. This research was conducted in the Kaleosan area of North Minahasa Regency, in North Sulawesi Province, Indonesian, which has a manifestation of hot water with a temperature of 90˚C with pH of 6.89, and there are silica deposits around it, all of which are characteristics of a water-dominated geothermal reservoir. This research was carried out by analyzing the characteristics of the surface fluid samples of the Kaleosan hot water manifestations. Analysis of fluid characteristics using the Cl-SO₄-HCO₃ and Na-K-Mg. From the Cl-SO₄-HCO₃ diagram, it is found that the geothermal fluid in Kaleosan is a type of chloride. The high chloride content is thought to be due to the increase in geothermal fluids containing CO₂ and condensing in shallow aquifers. From the Na-K-Mg diagram, it is obtained that the Kaleosan hot springs are immature water where this manifestation fluid has undergone dilution and cooling by meteoric water during its trip to the surface. From the quartz silica geothermometer, the reservoir temperature estimate is 236.6˚C, which indicates that the geothermal reservoir in the Kaleosan area is a high enthalpy geothermal system.

1. Introduction
Indonesia is one of the countries with considerable geothermal potential in the world. Indonesia's geothermal potential reaches 29,000 MWe spread across the region or around 40% of the world's geothermal potential. However, the utilization of geothermal energy in Indonesia has only reached 1.341 MW for electricity generations or 4.6 % of the total potential [1]. This indicates that geothermal energy in Indonesia still needs to be developed in the exploration and exploitation stages. Geothermal energy is associated with volcanic areas and plate subduction because it is at the junction of 3 (three) large plates. Indonesia, which is on the ring of fire route, shows a source of sub-surface heat in the form of magmatic. North Sulawesi is one of the areas on the ring of fire route. Geothermal development in North Sulawesi is sufficient. The development of power plants by PGE and PLN with a power of 4 x 20 MW in Lahendong and 2 x 20 MW in Tompaso has supplied electrical energy to the people of North Sulawesi.

The increasing need for energy demands the development of science to continue to exploit optimally the areas where the potential for geothermal energy has been developed. The prospect area will continue to be explored, especially areas that have geothermal manifestations. The Kaleosan area in Minahasa Regency is the target of research because it has geothermal manifestations such as hot springs, steaming ground, silica deposits, and others.
In contrast to the oil-gas system, the existence of a geothermal resource below the surface is often indicated by the presence of geothermal surface manifestations, such as hot springs, mud pools, and geysers, and other geothermal manifestations. Geothermal manifestations on the surface are thought to occur due to the propagation of heat from below the surface or because of the fractures that allow geothermal fluids (steam and hot water) to flow to the surface [2]. In addition to an indication of the fluid that comes to the surface as the manifestation of geothermal energy can also be analyzed from mineral rocks. Rocks that undergo changes due to reactions with the geothermal manifestation fluid are called altered rocks. The alteration process, which occurs due to contact with geothermal rocks and fluids, can cause mineral replacement or direct mineral deposition in the rock pores. Hydrothermal alteration minerals found in rocks can be an indicator in analyzing temperature, permeability, and other physical properties of geothermal fluids [3].

Hot water can come from a hot water reservoir deep below the surface or it may also come from groundwater which becomes hot due to heating by hot steam. When the water comes from a geothermal reservoir, it is almost always neutral. The water is generally clear and bluish in color. If the water comes from groundwater which becomes hot due to heating by hot steam, then the water in hot water pools is generally acidic. This acidic nature is due to the oxidation of H₂ in hot steam. Acidic hot water pools are generally muddy and greenish. Acidic hot water pools may be above a hot water reservoir [2].

2. Methods

2.1. Types of geothermal manifestation fluid

The type of fluid can be determined based on the content of the most dominant chemical elements found in hot water and the physical processes that occur [4]. The type of manifest fluid can be determined by Cl-SO₄-HCO₃ trilinear diagram (Figure 1).

![Cl-SO₄-HCO₃ trilinear diagram](image)

**Figure 1.** Cl-SO₄-HCO₃ trilinear diagram [4].

Here are some types of fluids from hot water, namely:

2.1.1. Chloride. This type of hot water is a type of fluid water in high temperature systems. Areas containing heat, heat sources and large fluid concentrations from deep reservoirs as well as in the permeable zone. The gas content is hydrogen sulfide with a relatively neutral pH. High chloride
concentrations indicate if the fluid comes directly from a reservoir where only a small amount of fluid experiences mixing.

2.1.2. Sulfate. This type of water is also called acid-sulfate water, which is formed due to the condensation of geothermal gases near the surface. Although it is always found at the surface (<100 meters), sulfuric water can penetrate more than due to faults through the geothermal system, then it is heated causing alteration in rocks and mixing with fluorid fluids. This type is often found in water that is cloudy or muddy. Sulfate is the main anion formed by the oxidation of hydrogen sulfide, resulting in a pH of about 2.8.

2.1.3. Bicarbonate. This type of water is some type rich in CO$_2$ fluid or also called neutral bicarbonate water which is produced by condensing water vapor and gas into the poorly-oxygenated sub-surface. This type is non-volcanogenic and a high temperature system with a pH approaching neutral due to reactions with surrounding rocks. Sulfate is produced in a certain amount and a small amount of chloride. This type can be formed as a result of several processes, namely water coming out near the surface of the oxidation of H$_2$S in chloride water, condensation of magma in the earth, or evaporation or formation of sulphur minerals.

2.2. Geothermal reservoir fluid balances

This method was developed by Gigenbach [5] by plotting Na/1000-K/100-$\sqrt{Mg}$ in a triangle diagram (Figure 2). This geothermometer combines two other geothermal equations, namely Na/K and K-Mg. Na/K represents the slow equilibrium reaction process in the reservoir, while K-Mg represents the fast equilibrium process in the area near the surface. Thus this geothermometer can be used to evaluate inside the reservoir as well as at the near surface level.

For fluid samples generated from boreholes such as in exploration drilling, generally contain very small Mg and in this diagram basically the Na/K equation plays a role. However, it needs to be remembered again that the Gigenbach Na/K geothermometer produced the highest value among other equations. So to see the sensitivity of the calculation results with other equations it is necessary to compare the Na/K geothermometer.

![Na-K-Mg trilinier diagram](image-url)
3. Results and discussion
The results of physical measurements of hot springs in Kaleosan can be shown in Table 1.

*Table 1. Physical measurement of hot water.*

| Air Temperature | Manifestation Temperature | Manifestation pH | Descriptions |
|-----------------|---------------------------|------------------|--------------|
| 33°C            | 93°C                      | 6.89             | Bubbles, clear bluish water, smells of sulfur, and there are silica deposits |

Based on Table 1, hot water in the Kaleosan area with a temperature of 93°C, normal pH, clear fluid, and silica deposits, all of which characterize the water-dominated geothermal reservoir type. Water-dominated reservoirs are a common reservoir type found in Indonesia, except in Kamojang and Darajat which are steam-dominated geothermal fields. The Lahendong geothermal area, which is the closest geothermal field to Kaleosan, has a water-dominated reservoir type.

From the chemical content of Kaleosan hot water fluid, it is then plotted on the Cl-SO\(_4\)-HCO\(_3\) trilinier diagram (figure 3) and Na-K-Mg trilinier diagram (figure 4). Cl-SO\(_4\)-HCO\(_3\) trilinier diagram is used to determine the type of thermal waters, and Na-K-Mg trilinier diagram is used as a geoindicator for mixing geothermal fluid with groundwater [6].

*Figure 3. Cl-SO\(_4\)-HCO\(_3\) trilinier diagram of kaleosan geothermal manifestation.*

Based on the plotting diagram, ternary shows that the meeting point is in the chloride area, which shows that the type of fluid manifestation of hot springs in the Kaleosan area is the type of chloride with a predominance of Cl ions. High chloride content indicates that the fluid has mixed with surface fluid but is still dominated by fluid originating from the reservoir [11].

The Na-K-Mg diagram is used to show the fluid balance of the geothermal reservoir [8]. Based on the results of the calculation of the relative content of Na/1000-K/1000-Mg and after plugging the results of the value on the Na-K-Mg triangle (Figure 4). Kaleosan hot springs are located in immature water,
showing that the temperature of the manifestations that appear on the surface tends to be low and is influenced by the interaction between hydrothermal fluids and elements such as silica. High Mg content is caused by mixing geothermal fluids with low Mg content and surface fluids with high Mg content [9]. This condition also shows that the reservoir rock is located in conditions of high temperature and pressure where before it reaches the surface it has also been diluted by surface water.

Figure 4. Na-K-Mg trilinier diagram of kaleosan geothermal manifestation.

Furthermore, from the chemical analysis, the temperature (T) of the reservoir can be estimated. Determination of reservoir temperature is very important, because the potential for geothermal is very large if the reservoir has a high temperature. For the calculation of reservoir temperature estimates using a quartz silica geothermometer because the fluid is immature water [10]. Quartz geothermometers are best used in reservoirs that have temperatures above 150°C [11]. The geothermometer equation of quartz silica from Arnorsson is suitable for geothermal manifestations. The equations for the Arnorsson quartz silica geothermometer are as follows:

\[ T = 53,500 + 0,11236C - 0,5559 \times 10^{-4}C^2 + 3,1665 \times 10^{-7}C^3 + 77,034 \log C \]

Where C is the silica concentration (mg/kg).

From the quartz silica geothermometer, an estimate of the reservoir temperature is 236.6°C which indicates that the geothermal reservoir in the Kaleosan area is a high enthalpy geothermal system. According to the Hochstein classification, a reservoir with a temperature above 225°C is a high enthalpy reservoir [12], so the Kaleosan area has the potential for future geothermal development.

4. Conclusions

- The manifestation fluid type of Kaleosan hot springs is chloride type. This shows that the fluid has mixed with surface fluid but is still dominated by fluid originating from the reservoir.
- Kaleosan hot springs are immature water, showing that the temperature of the manifestations that appear to the surface tends to be low and is influenced by the interaction between hydrothermal fluids and elements such as silica. This condition also shows that the reservoir rock is located in conditions of high temperature and pressure where before it reaches the surface it has also been diluted by surface water. High Mg content is caused by mixing geothermal fluids with low Mg content and surface fluids with high Mg content.
- The calculation of reservoir temperature in the Kaleosan area using a quartz silica geothermometer is 236.6°C. According to the Hochstein classification, a reservoir with a
temperature above 225ºC is a high enthalpy reservoir, so the Kaleosan area has the potential for future geothermal development.

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