Reservoir Temperature Calculation of Immature Geothermal Water from Hot Spring Around the Slamet Volcano

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Abstract. The temperature of some geothermal reservoirs around Slamet Volcano can be estimated from hot spring water geochemistry around it. Calculation of reservoir temperature from immature hot water samples has the potential to cause uncertainty. This is due to a mixture of geothermal water and meteoric water. The manifestation of the geothermal water appears in several different places, including on the southern slope of Slamet Volcano which consists of Pancuran-7 and Pancuran-3 Hot Springs. On the northwest slope of Slamet Volcano, several manifestations also appear, namely Pancuran-13 and Pengasihan in the Guci Area and Sigedong Hot springs in Sigedong Area. This study uses geochemical methods of geothermal water and hot springs water sample data from previous studies for analysis of geindicators and geothermometers. Reservoir temperature calculation is based on the content of silica and enthalpy of immature geothermal water and meteoric water in the study area. Based on the Cl-Li-B geindicator analysis, it was interpreted that there were 3 geothermal systems with different reservoirs around Slamet Volcano, namely the Baturaden, Guci and Sigedong Systems. Based on the Na-K-Mg plot for the geothermometer, the five hot springs around Slamet Volcano are included in the immature water group. Based on the enthalpy vs. silica analyses, the geothermal reservoir temperatures for Baturaden, Guci, and Sigedong are 204°C-210°C, 187°C-196°C and 181°C.

1. Introduction
Some volcanoes in Indonesia have the potential of geothermal energy resources. Geothermal energy potential stored in the area around volcano forms a geothermal system composed of heat sources, reservoir rocks, cap rocks, and geothermal fluids. Geothermal reservoir is one of the important aspects in which there are fluids heated by a heat source. This fluid then rises to the surface through existing rock fractures [1]. In general, the calculation of the temperature of the geothermal reservoir uses the geothermometer method. This method is difficult to do if hot springs have immature water conditions. This research was conducted to determine the temperature of geothermal reservoirs from hot springs that are in immature water conditions.

This research was conducted in the geothermal area of Slamet Volcano, Central Java. In Slamet Volcano, Central Java, an indication of the geothermal system is recorded as a hot spring at some points. On the southern slopes, Pancuran-3 and Pancuran-7 Hot spring are in the Baturaden area. On the northwest slope, Pancuran-13 and Pengasihan hot springs are in the Guci area.
In addition to the Guci area, on the northwestern slope, there is also a hot spring in the Sigedong area called the Sigedong Hot spring. This study also uses three output points of cold water located around the hot springs. The research location can be reached by using two or four-wheeled vehicles about 1-2 hours from the Geology Campus, Jenderal Soedirman University (Unsoed) in Purbalingga. Location of the study as shown in Figure 1.

2. Regional Geology
The research area which is part of the Slamet Volcano Complex is composed of several units of the rock which derive from Slamet Volcano Eruption Products [2]. The oldest rock unit in the study area is the lava flow of Mingkrik which is composed of whitish-gray andesite black spots with a composition of plagioclase and pyroxene. On top of the Mingkrik lava deposited the lava flow of Kalipaggu which is composed of whitish-gray andesite to dark black. Those two oldest rock units in the study area are classified as old Slamet Volcano eruption products group. The above of the old rock group deposited the younger Slamet Volcano eruption products group which was also composed of several rock units. The oldest unit in these younger group is the pyroclastics fall of Angrun which is composed of bombs, lithic, and scoria of sand size to lapilli. The second deposited unit of these younger rock group is the pyroclastic fall of Slamet which is divided into 3 based on the deposition site. This unit is composed of scoria with sand and lapilli size in red/gray. The youngest unit of these younger group is the Slamet lava flow which is also divided into 3 based on the deposition site. The Slamet lava flow is composed of a blackish gray vesicular structure basalt.

The youngest rock unit in the study area was composed of andesite blocks transformed by hydrothermal processes. Based on the geological cross section of Mount Slamet [2], five hot springs of the study area were found in volcanic rocks in the form of lava and lava avalanches that covered the marine sedimentary rocks of Tapak, Kumbang, Halang, Rambatan dan Pemali Formations (Figure 2).
Figure 2. Geological map of the study area [2]

3. Method
The method used to determine the temperature of the geothermal reservoirs around Slamet Volcano is geochemical method. This method uses chemical data of water came from hot springs and meteoric water output in the study area. Chemical data of hot water and meteoric water used in this study are sourced from previous researchers [3] and [4]. Chemical data for each hot water is used for initial analysis as a material for consideration when determining the temperature of a geothermal reservoir. The initial analysis was carried out by analyzing the water type with the ternary diagram Cl-SO₄-HCO₃ [5], analyzing the geothermometer of Na-K-Mg [6] and Cl-Li-B geoidicator. Further analysis carried out in determining the temperature of the geothermal reservoir using enthalpy vs. silica diagrams [7].
Based on the enthalpy value and silica content of the water samples from the hot springs and meteoric water in the study area, the enthalpy value of the reservoir is obtained. Then, reservoir temperature can be obtained after reservoir enthalpy values from the steam able data known [5].

4. Results and Discussion

Geothermal manifestations around Slamet Volcano appear as hot springs at several points in the study area. There are three different regions where hot springs appear. In the Baturaden area on the southern slope of Slamet Volcano, two hot springs appeared, namely Pancuran-3 and Pancuran-7 Hot Springs. On the northwest slope of Slamet Volcano, hot springs also appeared, namely Pancuran-13 and Pengasihan Hot Springs in Rembul area and Sigedong Hot Spring in the Sigedong area. From the five hot springs, several analyses were carried out, namely the type of water, geotermometer and geoindicator to determine the temperature of the geothermal reservoir in the study area. The data used in the analysis are data on the chemical content of the ions of each hot spring and meteoric water (Table 1).

| Component (mg/l) | Pancuran-7 [3] | Pancuran-3 [3] | Pancuran-13 [3] | Pengasihan [3] | Sigedong [4] |
|-----------------|----------------|----------------|-----------------|----------------|--------------|
| Temperature (°C)| 50             | 46             | 40,5            | 50,4           | 41,5         |
| Na              | 389            | 377            | 57              | 129            | 61           |
| K               | 76             | 77             | 24              | 36             | 17           |
| Mg              | 185            | 185            | 29,8            | 46,1           | 11,04        |
| Ca              | 193,5          | 196,5          | 28,9            | 40,1           | 40,92        |
| Li              | 0,67           | 0,58           | 0,02            | 0,06           | 0,08         |
| B               | 4              | 4              | 3               | 7              | 1            |
| Cl              | 754            | 724            | 17              | 44             | 20           |
| SO₄             | 609            | 600            | 33              | 89             | 3            |
| HCO₃            | 687            | 695            | 346             | 549            | 335          |
| SiO₂            | 169            | 164            | 121             | 135            | 128          |

To determine the temperature of the geothermal reservoirs in the study area, the first thing to do is to know the type of water from each hot spring. Chemical data used in determining the type of water are chloride (Cl), sulfate (SO₄) and bicarbonate (HCO₃). The three ions are plotted in a triangle to determine the position of each hot spring. The plotting shows that the type of water MAP Pancuran-13, MAP Pengasihan, and MAP Sigedong is bicarbonate (HCO₃) water type.

This water type is resulted from dilution of chloride water with meteoric water or bicarbonate water when flowing to the surface. MAP Pancuran-3 and MAP Pancuran-7 are chloride-sulfate-bicarbonate water type or chloride water which have been mixed with sulphate and bicarbonate water. The ternary diagram Cl-SO₄-HCO₃ is shown in Figure 3.
The important thing to do to determine the temperature of the geothermal reservoir is knowing which water is included in the hot spring of the research area, whether it is immature water, partial equilibrium or full equilibrium. Calculation of reservoir temperature in manifestations with immature water conditions using the Na-K or K-Mg graphic geothermometer method (Figure 4) needs to be rechecked with another calculation method. This is due to the presence of large meteoric water which is characterized by high Mg values that no longer reflect reservoir fluids.

The indication of the presence of immature water can be known also by using the ratio of sodium (Na), potassium (K) and magnesium (Mg) to be plotted in the ternary diagram. The plotting shows that the five hot springs water of the study area are included in the immature water group, which means that it is difficult to use to determine reservoir temperature by the usual geothermometer method (Figure 4).

Another thing that needs to be considered in determining the temperature of the geothermal reservoir is to find out the number of geothermal systems that work in the study area so that the number of reservoirs is known. If there is more than one reservoir, the determination of reservoir temperature is also carried out more than once.

The determination of the number of geothermal systems is carried out in a linear geoindicator diagram by plotting chloride (Cl), lithium (Li) and boron (B) ions. The plotting shows the position of each hot springs on the geoindicator diagram (Nicholson, 1993). Plotting results showed three hot spring groups (there are three geothermal systems), namely Baturaden (MAP Pancuran-3 and Pancuran-7), Guci (MAP Pancuran-13 and Pengasihan), and Sigedong (MAP Sigedong) [3] and [4]. This analysis can be seen in Figure 5.

The existence of three different geothermal systems can also be interpreted from the location and lithology of the emergence of hot springs from the three different systems. The Baturaden, Guci, and Sigedong systems are located in the southeast, north and northwest part of the research location map. The three systems raises hot springs in lithology of Slamet lava flow, Guci deposits and Slamet pyroclastic fall deposits (Figure 2).

Based on geoindicator analysis, it is known that there are three different geothermal reservoirs in the study area, so there will be three calculations of geothermal reservoir temperatures. Whereas based on geothermometer analysis, the five hot springs are immature water which is difficult to use to determine reservoir temperature by ordinary methods, so that other methods are used to determine reservoir temperature. The method used is the enthalpy vs. silica diagram method.
Figure 5. Geoindicator of hot spring in the study area.

Figure 6. Enthalpy vs. silica content diagram of Baturaden reservoir.
Figure 7. Enthalpy vs silica content diagram of Guci reservoir.

Table 2. Calculation of reservoir temperature using the Silica-Entalpy and Na/K methods [5].

| No. | Manifestation | Si-enthalpy | Na/K   |
|-----|---------------|-------------|--------|
| 1   | Pancuran-7    | 204         | 280 [3]|
| 2   | Pancuran-3    | 210         | 286 [3]|
| 3   | Pengasihan    | 187         | 429 [3]|
| 4   | Pancuran-13   | 196         | 340 [3]|
| 5   | Sigedong      | 181         | 340 [4]|

This diagram uses the enthalpy value and the silica content of water from hot springs and meteoric water to calculate the temperature of the geothermal reservoir. The Enthalpy-silica diagram is a simple technique for estimating the temperature of hot water that has been mixed with cold water. This method is based on the equilibrium of the silica content at a certain temperature [5]. There are two assumptions that can be used in the silica enthalpy diagram. The first assumption is maximum steam loss if there is heat loss from the fluid during fluid travel from the reservoir to the surface. The second assumption is no steam loss if there is no heat loss to the reservoir fluid. The springs of the study area show temperatures that are quite low so that they are used as an indication for the maximum steam loss assumption.

The silica enthalpy diagram begins with the plotting of enthalpy and silica content of hot spring and meteoric water into the diagram. The enthalpy and silica data entered must agree with data taken at the same time and located on the same geothermal system for each hot spring. For the Baturaden reservoir, after the MAP Pancuran-3 and Pancuran-7 data are plotted in the diagram, a regression line of hot spring and meteoric water points is made. Then the regression line is continued to cut the vertical line of the boiling marker (419 kJ/k). The intersection point is called Point B. From point B, a horizontal line is made to cut the maximum steam loss curve. The intersection point is called the PT Point. From the PT
point, vertical lines are made towards the enthalpy axis so that the enthalpy value for MAP Pancuran-7 is 870 kJ/kg and MAP Pancuran-3 is 897 kJ/kg. From the enthalpy value, it is known that the temperature of the Baturaden reservoir ranges from 204°C – 210°C (Figure 6).

It is the same steps for Guci and Sigedong reservoirs. For the Guci reservoir, the enthalpy value is obtained at 834.5 kJ/kg and MAP Pancuran-13 is 794.3 kJ/kg. From the enthalpy values, it can be seen that the temperature of Guci reservoir is 187°C-196°C. Sigedong reservoir has an enthalpy value of 767 kJ/kg which represents the reservoir temperature of Sigedong is 181°C. Temperature determination graph for Guci and Sigedong reservoir can be seen in Figure 7 and 8.

There are differences between the two calculations using two different methods. The presence of meteoric water in samples causes uncertainty and large values in calculations using the Na/K geothermometer method, as shown in the plotting of the major elements. Figure 4. Temperature reservoir calculation using the silica-enthalpy method shows a value smaller than the temperature value from the calculation of the geothermometer Na/K method, this is shown in Table 2.

Reservoir temperature calculation using the Na / K geothermometer method gives a very high value, even up to 340°C - 429°C (Table 2). The presence of fumaroles at the summit of Mount Slamet indicates a high temperature system with a reservoir temperature of around 250°C (upflow zone). Reservoir temperature calculation using the silica-enthalpy method gives more accurate values than others even though it must be rechecked with another method.

5. Conclusion
The five hot springs of Pancuran-7, Pancuran-3, Pancuran-13, Pengasihan, and Sigedong in the study area are in immature water. This condition indicates that a process has occurred which causes the geothermal fluid to be unbalanced. This condition makes hot springs is difficult to use in determining reservoir temperature by the geothermometer method. Based on the geoidicator analyses, there are three geothermal systems that work in the study area, namely Baturaden, Guci, and Sigedong systems or reservoir. Recalculation of geothermal reservoir temperatures in the study area for Batudaren, Guci, and Sigedong using the silica-enthalpy method were 204°C - 220°C, 187°C - 196°C and 181°C.

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