Investigation of alteration minerals and potential of geothermal energy on the Ambon Island

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Abstract. An investigation of alteration minerals has been carried out using the XRD (X-ray diffraction) method in several geothermal areas on Ambon Island. There are 4 (four) regions that are mapped as potential areas for the development of geothermal energy in Ambon islands, including Hatuasa geothermal energy, TalangHaha, Suli, and Waiyari. The results of the investigation interpret that rock samples in the Hatuasa geothermal region are dominated by quartz wacke with rock fragments in this area in the form of quartz minerals, pyroxene, opaque minerals, and feldspar while the matrix is clay minerals. The interpretation of rock samples in the TalangHaha, Suli and Waiyari regions is almost the same which is dominated by feldspathic greywacke with fragments in the form of quartz minerals, opaque minerals, lytic, and feldspar, while the matrix is clay minerals. Those minerals are alteration minerals from the original minerals. The appearance of mineral changes in these areas shows that the reservoir temperature in these areas is very high. In addition to changes in the appearance of minerals, the potential of geothermal energy in some areas of Ambon Island can also be interpreted from the results of measurements of flowrate. Flow discharge in the Hatuasa, TalangHaha, Suli and Waiyari regions ranged from 0.19 m\(^3\)/second; 0.16 m\(^3\)/second; 0.13 m\(^3\)/second and 0.20 m\(^3\)/second give the results of heat loss calculations which are 86.4 kW; 71.8 kW; 72.4 kW and 114.19 kW. Thus the Hatuasa, TalangHaha, Suli and Waiyari geothermal fields can be used as a basis for recommendations on the utilization of geothermal potential for local governments (indirect use), namely as information to meet the shortage of electricity in Ambon Island.

1. Introduction
Geothermal energy is natural energy produced in the form of hot water or steam formed in a reservoir inside the earth through subsurface water heating by freezing magma. The existence of geothermal energy is characterized by several surface heat manifestations in the form of: hot springs, mud pools, fumaroles, solfatara and alteration rocks. Heat energy that is owned by hot water or hot steam basically comes from magma in the bowls of the earth which propagates its heat conduction, forming a convection system that produces hot water or hot steam. This condition tends to make hot water move to the surface of the earth and trapped under impermeable rock which functions as a cap rocks so that a geothermal energy reservoir is formed with a dominance system of steam or water dominance, which has a high pressure and temperature. The existence of a rock fracture system or...
because of the propagation of heat from the subsurface allows the movement of hot water or hot steam to the surface of the earth [1].

Hatuasa, TalangHaha, Suli and Waiyari are geothermal prospect areas. Those are formed by result of normal fault movement activities from directed Northeast-Southwest to Leihitu district [2]. Geographically, the Hatuasa hot spring is located at UTM coordinates (x = 423140; y = 9602910) with an altitude of 105 m above sea level. TalangHaha hot spring is located at UTM coordinates (x = 423218; y = 9602814) with an altitude of 110 m above sea level. Hatuasa is only 200 m from TalangHaha. Geographically, Suli's hot springs are located at UTM coordinates (x = 423218; y = 9602814) with an altitude of 110 m above sea level.

Basically, this research was conducted to determine the type of alteration minerals by analyzing rock samples taken from hot springs in the Hatuasa, TalangHaha, Suli and Waiyari regions. Rock samples were analyzed using the XRD method with bulk analysis (analysis of powder and clay analysis).

In addition, Hochstein & Browne (2000) suggest that geothermal system activity is generally related to the formation of hydrothermal alteration minerals. The Alteration minerals can be used as an indicator to find out the area that has geothermal potential. Hydrothermal alteration is a feature of texture changes, mineralogy and the chemical composition of rock caused by hydrothermal fluid activity [3].

Harvey and Browne (1991) suggest that a conclusion that is directly deposited on the temperature (190-220)°C is closely related to the rock more permeable whichillite has a low temperature [4]. In-depth research on the physical properties of Hatuasa hot water, TalangHaha, Suli and Waiyari to estimate heat loss was calculated based on measurements of hot water discharge around the Hatuasa, TalangHaha, Suli and Waiyari hot springs. So that it can be used as a basis for recommendations on the utilization of geothermal potential for local governments (indirect use), namely as information to meet the shortage of electricity in Ambon Island.

Marini and Susangkyono (1999) [5] state that currently Indonesia has a total potential of geothermal resources and reserves of 27,189 MW (i.e. potential of 14,244 MW, estimated reserves of 9,912 MW, maybe 728 MW, and proven 2,305 MW) or around 40 % of the world's potential. Nevertheless, only 807 MW of the total potential is utilized to meet Indonesia's electricity needs.

2. Research Methods

Investigation of alteration minerals in the Hatuasa, TalangHaha, Suli and Waiyari geothermal regions was carried out by analyzing rock samples using XRD method with bulk analysis (analysis of powder and clay analysis). XRD analysis results, a pattern that could explain the existence of minerals deposits in the study area. The rock samples taken and from each geothermal area were then analyzed to determine the composition of mineral constituents of rock in geothermal regions. In addition, from the analysis results obtained images of incisions that show the texture and fragments of rocks, so that it can be seen the spread and characteristics of alteration rocks formed on the surface [6].

This study estimates the potential of geothermal energy through the calculation of heat loss which is calculated based on the measurement of the flow of hot water around the spring. This natural heat loss is calculated based on the formula given by Hochstein (1990) in Saptadji (2009) [7], namely:

\[ Q = m \left( h \cdot f \cdot T - h \cdot f \cdot T_0 \right) \approx m \cdot c \cdot (T - T_0) \]  

with: \( Q \) is heat loss (kW); \( m \) is the outflow flow (m³/second); \( h \cdot f \cdot T - h \cdot f \cdot T_0 \) is fluid enthalpy (kJ / kg); \( c \) is specific heat capacity (kJ/kg.°C), \( c \) for water has an average value of kJ/kg.°C; \( T \) is the temperature of the hot spring and \( T_0 \) is the average annual air temperature.

Calculation of natural heat loss is calculated according to the type of heat manifestation of the earth. For hot or warm water pools, the calculation of heat loss must take into account the evaporation process. For ponds that have dimensions of less than 1000 m², an empirical approach is generally used with natural heat loss values that are in accordance with the pool temperature.
3. Results And Discussion
The results of analysis of rock samples in the Hatuasa, TalangHaha, Suli and Waiyari geothermal areas using XRD method with bulk analysis (analysis of powder and clay analysis), among others: Figure 1.a shows a description of thin incisions namely clastic texture, open container, bad sorting, measuring <0.03 - 0.8 mm, angular-subrounded grain shape, composed of fragments and matrices. Fragments are quartz minerals, pyroxene, opaque minerals, and feldspar, while the matrix is clay minerals.

The composition description shows feldspar, colorless color, brownish white interference color, 0.3-0.5 mm size, 1-way hemisphere, no twinning, sub-angular shape, 12% abundance in rocks; quartz, colorless mineral and yellow interference color, has no hemisphere, sub rounded shape, size 0.05-0.2 mm, with the position of wavy darkness, rock abundance is 42% in rock; pyroxene, this mineral is brownish white in parallel and blue in Nikol crossed, its size is 0.3 - 0.5 mm, tapular shaped tapered, the relief is high, there are fractions, divisions are two directions, there is high pleikroism, the color of the interference is orange, the angle of darkness 33 ° or tilted, abundance in 6% incision; opaque mineral, black color, black interference color, size 0.4-0.7 mm, no hemisphere, even distribution, 10% abundance in rocks; clay minerals, grain size <0.03 mm, 30% abundance, even distribution. So it can be interpreted that the results of the analysis of rock samples in the Hatuasa geothermal region are quartz wacke.

Figure 1.b shows a description of a thin incision namely clastic texture, open container, bad sorting, size <0.03 -1 mm, subangular-subrounded grain shape, composed of fragments and matrices. Fragments are quartz minerals, pyroxene, opaque minerals, and feldspar, while the matrix is clay minerals. Composition description shows quartz, grain size 0.1-0.5 mm, subangular-subrounded crystal shape, 7% abundance, uneven distribution; pyroxene, grain size 0.5-1 mm, subangular-subrounded crystal shape, 8% abundance, uneven distribution; Opak minerals, grain size 0.5-0.8 mm, angular-subrounded crystal shape, 11% abundance, uneven distribution; feldspar, grain size 0.5-1 mm, subangular-subrounded crystal shape, 27% abundance, uneven distribution; clay minerals, grain size <0.03 mm, 47% abundance, even distribution. So it can be interpreted that the results of the analysis of rock samples in the TalangHaha geothermal area are feldspathic greywacke.

Figure 1.c shows a description of a thin incision namely clastic texture, open container, bad sorting, size <0.03 -1 mm, subangular-subrounded grain shape, composed of fragments and matrices. Fragments are quartz minerals, opaque minerals, lytic, and feldspar, while the matrix is clay minerals. Composition description shows quartz, grain size <0.1-0.7 mm, subangular-subrounded crystal shape, 5% abundance, even distribution; Opak minerals, grain size 0.2-0.5 mm, angular-subrounded crystal form, 10% abundance, even distribution; lytic, gray color, size 0.8-1 mm, composed of feldspar and quartz, abundance of 5%, uneven distribution; feldspar, grain size 0.5-1 mm, subangular-subrounded crystal shape, 20% abundance, uneven distribution; clay minerals, grain size <0.03 mm, 55% abundance, even distribution. So it can be interpreted that the results of the analysis of rock samples in the Suli geothermal region are Feldspathic greywacke. This result is the same as that stated by Andayany (2015) that the petrographic analysis to rock samples located at Waiyari Geothermal was dominated by feldspathic greywacke. Another alteration mineral types in this area are quartz, opaque, lithic, and feldspar minerals. The mineral minerals show that the mineral types of origin rock is sandstone tuff. The method of analysis is that the alteration minerals are generally dominated by the presence of metals such as illite-chlorite with particle size (<0.03 mm), the abundance of 55% and the spread evenly [8].

Figure 1.d shows a description of a thin incision, namely clastic texture, open container, bad sorting, size <0.03 -1.5 mm, subangular-subrounded grain shape, composed of fragments and matrices. Fragments are quartz minerals, opaque minerals, lytic, and feldspar, while the matrix is clay minerals. Composition description shows quartz, grain size <0.1-0.5 mm, subangular-subrounded crystal shape, 7% abundance, even distribution; Opak minerals, grain size 0.5-0.8 mm, angular-subrounded crystal shape, 8% abundance, even distribution; lytic, gray, size 0.8-1.5 mm, composed of feldspar and quartz, 12% abundance, uneven distribution; feldspar, grain size 0.5-1 mm, subangular-subrounded crystal
shape, 18% abundance, uneven distribution; clay minerals, grain size <0.03 mm, 55% abundance, even distribution. So it can be interpreted that the results of the analysis of rock samples in the Suli geothermal region are feldspathic greywacke.

![Figure 1. The thin incision of rock samples of geothermal regions: a. Hatuasa; b. Talang Haha; c. Suli; d. Waiyari.](image)

The results of measurements of temperature, pH and conductivity of hot water on the surface of the Hatuasa, TalangHaha, Suli and Waiyari geothermal areas during monitoring 1 x 24 hours with a measurement interval of every 30 minutes is given in the table.

| Geothermal area       | Hatuasa | TalangHaha | Suli   | Waiyari |
|-----------------------|---------|------------|--------|---------|
| Parameters            | Value   | Value      | Value  | Value   |
| Temperature(°C)       | 56.4    | 52.4       | 60.2   | 60.0    |
| pH (± 0.01)           | 7.6     | 7.7        | 7.6    | 7.2     |
| Conductivity(μS/m)    | 0.240   | 0.150      | 0.245  | 0.210   |
| Flowrate(m³/second)   | 0.19    | 0.16       | 0.13   | 0.20    |
| Reservoir Temperature (°C) | 274   | 277        | 172    | 220     |
| Heat loss(kW)         | 86.4    | 71.8       | 72.4   | 114.9   |
Based on table 1, the measurement results of the average surface water temperature in the Hatuasa, TalangHaha, Suli, and Waiyari regions are 56.4°C, 52.4°C, 60.2°C, and 60.0°C respectively. The characteristics of hot water in the Hatuasa, TalangHaha, Suli, and Waiyari regions are also supported by pH, respectively 7.6, 7.7, 7.6, and 7.2, and electrical conductivity respectively is 0.240 (μS/m), 0.150 (μS/m), 0.245 (μS/m), and 0.210 (μS/m). In addition, the measurement of flow flows in succession of 0.19, 0.16, 0.13, and 0.20 m³/sec gives the results of heat loss calculations in these areas respectively are 86.4 kW, 71.8 kW, 72.4 kW, 114.9 kW whose calculation is given in table 2.

**Table 2. Results of calculation of natural heat loss in the Hatuasa geothermal area.**

| Station Code Of Measurement | Flowrate (m³/second) | T (°C) | T₀ (°C) | h.f. T (kJ/kg) | h.f. T₀ (kJ/kg) | Δhf (kJ/kg) | Q (kW) |
|----------------------------|----------------------|--------|---------|---------------|----------------|-------------|--------|
| H-1                        | 0.19                 | 56.4   | 29      | 235           | 120            | 115         | 21.9   |
| H-2                        | 0.18                 | 56.0   | 28      | 233           | 115            | 118         | 21.2   |
| H-3                        | 0.19                 | 56.2   | 28      | 234           | 116            | 118         | 22.4   |
| H-4                        | 0.17                 | 56.3   | 27      | 235           | 112            | 123         | 20.9   |
| Q total (kW)               |                      |        |         |               |                |             | 86.4   |

**Table 3. Results of calculation of natural heat loss in the TalangHaha geothermal area.**

| Station Code Of Measurement | Flowrate (m³/second) | T (°C) | T₀ (°C) | h.f. T (kJ/kg) | h.f. T₀ (kJ/kg) | Δhf (kJ/kg) | Q (kW) |
|----------------------------|----------------------|--------|---------|---------------|----------------|-------------|--------|
| TH-1                       | 0.16                 | 52.4   | 28      | 220           | 117            | 103         | 16.5   |
| TH-2                       | 0.17                 | 52.5   | 27      | 222           | 115            | 107         | 18.2   |
| TH-3                       | 0.17                 | 52.8   | 26      | 227           | 114            | 113         | 19.2   |
| TH-4                       | 0.16                 | 52.6   | 26      | 225           | 113            | 112         | 17.9   |
| Q total (kW)               |                      |        |         |               |                |             | 71.8   |

**Table 4. Results of calculation of natural heat loss in the Suli geothermal area.**

| Station Code Of Measurement | Flowrate (m³/second) | T (°C) | T₀ (°C) | h.f. T (kJ/kg) | h.f. T₀ (kJ/kg) | Δhf (kJ/kg) | Q (kW) |
|----------------------------|----------------------|--------|---------|---------------|----------------|-------------|--------|
| S-1                        | 0.13                 | 60.2   | 26      | 242           | 98             | 144         | 18.7   |
| S-2                        | 0.14                 | 60.5   | 27      | 244           | 103            | 141         | 19.7   |
| S-3                        | 0.13                 | 60.4   | 29      | 243           | 111            | 132         | 17.2   |
| S-4                        | 0.12                 | 60.2   | 27      | 241           | 101            | 140         | 16.8   |
| Q total (kW)               |                      |        |         |               |                |             | 72.4   |

**Table 5. Results of calculation of natural heat loss in the Waiyari geothermal area.**

| Station Code Of Measurement | Flowrate (m³/second) | T (°C) | T₀ (°C) | h.f. T (kJ/kg) | h.f. T₀ (kJ/kg) | Δhf (kJ/kg) | Q (kW) |
|----------------------------|----------------------|--------|---------|---------------|----------------|-------------|--------|
| W-1                        | 0.20                 | 60.0   | 27      | 246           | 107            | 139         | 27.8   |
| W-2                        | 0.21                 | 60.2   | 27      | 248           | 109            | 139         | 29.2   |
| W-3                        | 0.21                 | 60.1   | 28      | 247           | 112            | 135         | 28.4   |
| W-4                        | 0.22                 | 59.9   | 28      | 243           | 109            | 134         | 29.5   |
| Q total (kW)               |                      |        |         |               |                |             | 114.9  |
By direct measurement of high surface temperatures, pH, conductivity and flowrate on the surface of the hot springs, the temperatures of the Hatuasa, TalangHaha, Suli and Waiyari geothermal reservoirs are interpreted to be 274°C, 277°C, 172°C and 220°C respectively.

4. Conclusion

The quartz wacke and feldspathic greywacke are alteration minerals that dominate geothermal areas in Ambon Island. This is also supported by the appearance of the temperature of hot water on the surface of each Hatuasa, Talanghaha, Suli and Waiyari geothermal regions, respectively 56.4°C, 52.4°C, 60.2°C, 60°C. The appearance of mineral changes in these areas shows that the reservoir temperature in these areas is very high.

Based on the interpretation of reservoir temperature in the Hatuasa, TalangHaha, Suli and Waiyari regions respectively are 274°C, 277°C, 172°C, 220°C. Then the Hatuasa, TalangHaha and Waiyari regions include high-temperature geothermal areas. Whereas the Suli geothermal area includes a medium-temperature geothermal area.

Measurements of flowrate in each Hatuasa, TalangHaha, Suli and Waiyari geothermal regions are 0.19 m³/second, 0.16 m³/second, 0.13 m³/second, 0.20 m³/second. Furthermore, providing results of heat loss calculations in the Hatuasa, TalangHaha, Suli and Waiyari geothermal regions respectively are 86.4 kW, 71.8 kW, 72.4 kW and 114.9 kW given in the table. 2. Thus the Hatuasa, TalangHaha, Suli and Waiyari geothermal fields can be used as a basis for recommendations on the utilization of geothermal potential for local governments (indirect use), namely as information to meet the shortage of electricity in Ambon Island.

5. References

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